(Clayton)

THE HISTORY

OF

DEVONSHIRE SCENERY

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BY

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DEVONSHIRE SCENERY

AN ESSAY IN

GEOGRAPHICAL EVOLUTION

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PREFACE.

To geologists generally, but especially to those who are working in the same field, I hope these pages may be of interest and use, not only as the expression of conclusions to which I have come after many years' work in the County of Devon, but also as a summary of the problems presented by its complicated structure, and the various solutions of them which have been proposed.

Some of the views I have expressed are novel, and in certain instances I have felt compelled to dissent from explanations which others have offered. In such cases I have endeavoured to make clear my reasons for preferring a new interpretation of the facts observed, and have given references to the original papers concerned, so that the writer's arguments can be followed in full.

To students, I hope the book may be useful as supplying a simple connected narrative by which the facts of geology may be linked into a whole. This has been done in a different way by Professor Hull in his *Contributions to the Physical History of the British Isles*, and by Mr. A. J. Jukes-Browne in his book *The Building of the British Isles*. To both of these works, but especially the latter, I must acknowledge considerable indebtedness when dealing with distant parts of the kingdom.

By confining myself mainly to a single district, it has been possible to give references to sections and scenes which may be visited within the limits of one or two summer vacations; and Devonshire is not only the county with which I am most familiar, but serves my purpose best, by illustrating a greater number of geological principles than any other.

Geology is too frequently studied as a vast accumulation of disconnected facts, which have to be learnt before they are put together. My own experience is that it is better to begin with a connected story from the first. The science is made more interesting, the details become easier to remember, and the use and meaning of principles is better understood.

In writing the following pages I have used the minimum of technical language, with the object of making them suitable for the beginner and the ordinary reader who has no previous knowledge of the subject, but who cares to know how Devonshire came to be what it is.

If a few should be led to a further study of a fascinating science, or if a few should gain a keener pleasure in the open moors and wooded valleys, tumbling streams, and rugged coast line of Devon, by learning something of their history and meaning, the book will have fulfilled its aim.

In conclusion, I have to express my indebtedness to the maps and memoirs of the Geological Survey, to the numerous geologists who have worked in Devon, and especially to the various publications of Mr. W. A. E. Ussher.

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CHAPTER I.

Introduction.

The story of Devonshire scenery begins far back in the dim antiquity of geological time, when the distribution of land and water on the face of the globe was very different from what we see on modern maps; when mountain ranges stood where there is now the open sea, and when the very rocks which go to build some of the loftiest heights of to-day were yet unformed. Through all time, since the world assumed anything like its present condition of temperature, change has followed change, and each interval has left some record of its character, which may be read by those who know the language in which it is written.

We are thus enabled to reconstruct, often with great accuracy, the physical geography of the past, but, just as with human history, the further we trace things back the more fragmentary become our sources of information. The earlier documents have too often been more than half obliterated, others have been written in a language which we cannot at present translate with confidence, and some are so ambiguously worded that they seem equally open to more than one interpretation.

In the long story of Devonshire there are many contentious and difficult points which await solution. Some will, no doubt, in time be solved by the diligent co-operation of local geologists, others will perchance have to await the discovery

of clues to their interpretation in other parts of the world. To the man of science it is, of course, just these uncertainties which have by far the greatest interest, but, after all, they are mostly details, while the broad general facts are clear enough to satisfy the most determined sceptic. On the whole it is easy to see how, step by step, the rocks of Devon came to be where they are and what they are; how, age after age, the scenery was modified, and yet how the physical geography of one time was more or less determined by that which had gone before, until in the fulness of time, that which we see around us is the result of all the long and chequered past.

The historian who wishes to make plain the why and wherefore of the events which make up the story of a people cannot avoid dealing more or less with the nations with whom they came in contact. Neither can he well omit all account of the still earlier races from whom it is possible to trace the descent of those who form his theme. In the same manner if we are to correctly understand the geological records of our own county it is absolutely necessary to study in a general way the changes which have affected a wider area, sometimes even one which embraces considerable portions of the European Continent, or what is now the North Atlantic. In other words we must consider the physical geography of a much wider region and the place which Devon has occupied in each of the pictures we attempt to draw.

Time is not measured by centuries in geological history. It is divided into five great eras, and each of them is subdivided into a number of periods. The names of these divisions of time are derived in some cases from the living things whose fossil remains are characteristic of the age, in others from the geographical district in which the rocks formed during the period are best shown or were first studied, and in others from the kind of rock formed at the time in some typical district. Unfortunately the sequence and nature of the records differs greatly in different parts of the world, and various attempts have been made to reform the system of nomenclature in order to make it as applicable to the geology of Europe as it is to that of Great Britain, which was the cradle of geological science. But these changes are only creeping slowly into

our English text-books, so the old system and the familiar terms will be used in the following pages.

The first era is naturally the one about which least is known. Until recently no fossils had been found in its rocks except some markings which looked like worm tracks, but which might have been due to some other cause. Hence it was named the Azoic or Lifeless Era. But the series of rocks lying immediately above, and therefore presumably next in age, contain so large a variety of organisms and some so highly developed that it seems impossible on any theory of animal evolution to suppose they had no progenitors, a doubt which has been effectually settled by the discovery of several undoubted fossils in the earlier rocks of America. The term Azoic is therefore a misnomer, and its place is now being taken by the word Eozoic which means the dawn of life. The rocks formed during the time are frequently spoken of as Archaean, but they only peep up here and there through the later deposits, and the various exposures show such different features that there may really be a greater separation in time between the Eozoic rocks of one place and those of another than there is between the latest of them and the earliest deposit of the following great division of time. It seems, therefore, undesirable to give the same name to all, and make that a definite name, for fear that it should be taken to imply an identity of age which does not exist. The oldest fossil bearing system which lies above them is the Cambrian system, and the Eozoic rocks are therefore now generally classed together under the name Pre-Cambrian.

We know little of Pre-Cambrian geology. There were volcanoes from which great floods of lava were outpoured. There were seas or lakes in which beds of pebbles and sand and mud were laid down, but although the similarity of conditions is obvious there are not wanting numerous indications that the action of those forces which result in the wear and tear of the land and the deposit of sediments was more vigorous then than it is to-day.

We have no certain glimpse of Devon in Pre-Cambrian time. The serpentine rocks of the Lizard peninsula and the green and grey crystalline rocks which make up the country

by Salcombe, and reach from the Bolt Tail to beyond the Start, are believed by some geologists to be of Eozoic age. But there is no proof, and if the guess is correct they tell us no more than that volcanoes were busy in the district. As a matter of fact the rocks of both places belong to a great section known as Metamorphoric, which means that they have been profoundly altered. In neither case can we say what they originally were. Probably they were partly volcanic, partly sedimentary, but their original structures have been destroyed and even their mineral constituents rearranged. They are documents, so to say, in which new things have been written on faded sheets so that the older writing has become quite illegible. It is on the whole more likely that they belong to a much later time, and we shall consider them again when we come to discuss the period at which the changes were most probably brought about.

The second great era is known as the Palaeozoic, or time of the ancient forms of life. It covers a long and important series of events during which great alterations took place in the map of the world, and since changes in geography with their consequent effects upon climate and environment are among the most potent agents of animal variation, we find that at the end of the era the world's inhabitants had made great progress in evolution.

So far as the British area is concerned the era falls naturally into two divisions known as Protozoic, or first life, and Deutozoic, or second life. The history of each of these follows a definite course, so that they form a couple of cycles during the second of which the events of the first were repeated with curious similarity. Each began with a land surface occupying a large part of the British area. The sea then advanced over the plains and up the valleys, driving the coast line further and further towards the north and west until our area was mostly covered by the ocean waters. Rain and rivers, wind and wave, swept down the debris from the land and spread it over the sea bottom in sheets of gravel, sand and mud. Organic things contributed their quota in the form of shells, reefs of coral, and limestone mud until thousands of feet of new rocks had been laid

down. The long period of deposition was then converted into an upheaval, at first gentle and accompanied by broad undulations of the strata, but later on the ascent became more rapid and was attended by enormous crushing, folding, and crumpling of the earth's crust, lifting the new formed rocks higher and higher above the sea until they stood up as a series of ranges making a mountain chain comparable with the Alps or Rocky Mountains of to-day, and dominating, as those chains do, a continental land.

Protozoic time includes three periods which are generally known as Cambrian, Ordovician, and Silurian, but geologists have not yet come into complete agreement over the use of the second name. The beds now classed as Ordovician were formerly named Upper Cambrian by the great Cambridge geologist, Sedgwick, and were independently called Lower Silurian by Murchison, the head of the geological survey. For many years the followers of these two great pioneers adhered obstinately to the use of the name adopted by their chief. Finally, as agreement seemed impossible, it was reserved for Professor Lapworth to invent a new term. The word Cambrian is derived from the fact that rocks of this age were first studied by Sedgwick in North Wales. Murchison first investigated the Silurian rocks in South Central Wales, the district once inhabited by the tribe of Ancient Britons known as the Silures. The debatable deposits lay between the two, not only in order of time, but also geographically. This was the district where the Ordovici lived, why not bury the hatchet then, and agree to drop both Upper Cambrian and Lower Silurian, and give a distinct name to a series of deposits which bore no nearer relationship to either the previous series or the succeeding series than it did to the other. The reasonableness of the suggestion has been appreciated and there are now only a few, such as Sir A. Geikie, who still adhere to the Lower Silurian of his predecessor in office.

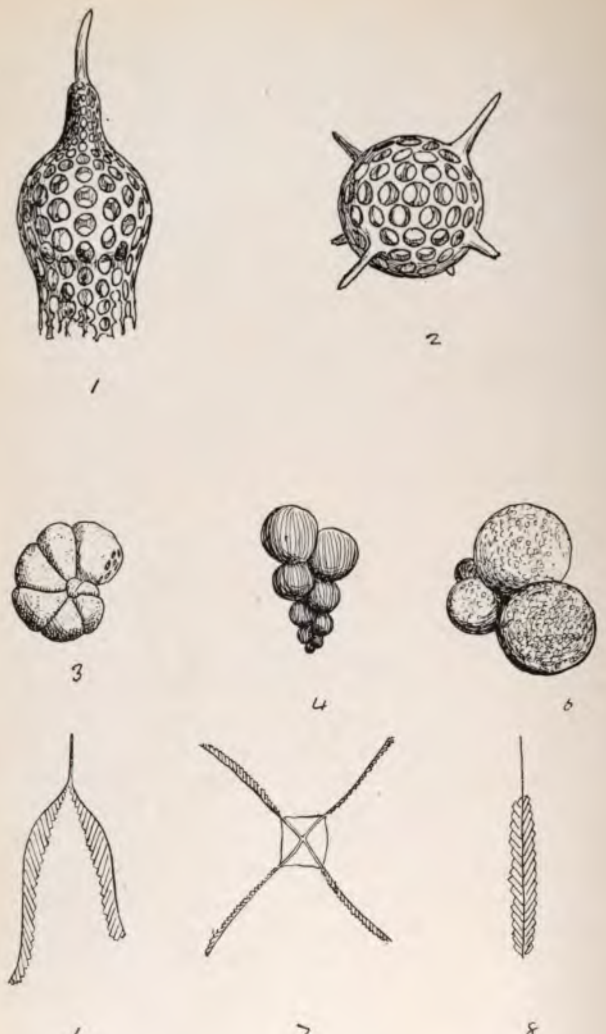
The Cambrian rocks bear abundant evidence of having been deposited at no great distance from a steep sloping shore in shallow water, and in shifting currents. Where their base can be seen they are often seen to rest on the upturned,

denuded edges of the earlier rocks, showing that they were formed on a submerged land surface. The upper beds of the system are finer and more evenly laid down, and consist of materials which would naturally have come to rest further away from the receding coast and in deeper water. They are interspersed with beds of lava and fine volcanic ash which suffice to show that in North Wales, at least, the volcanic activity so characteristic of Pre-Cambrian time was still alive. Indeed, much of the fine mud which made up the slates among which the undoubted volcanic rocks are found may very well have owed its origin to eruptive outbursts.

A study of the Cambrian rocks of other countries points to the remarkable conclusion that the great continent from which their materials were borne occupied the site of the Northern Atlantic, while the oceanic areas lay where Russia is on the one hand, and the Western States of America on the other.

The volcanoes of Cambrian days seem to have been a feebler link between two periods of intense action. Ordovician time witnessed the growth of several important groups of volcanic mountains in the British area, the chief of which occupied the site of North Wales, while another of almost equal importance marked the place now occupied by the English Lake district. Great floods of lava were poured out, and these alternated with vast deposits of volcanic ash which were spread far and wide over the floor of the sea. There is little doubt that these two districts formed volcanic islands built up from the ocean bottom like the Sandwich Islands and some of the West Indies of to-day. Like all other great volcanic piles they were built up of materials which varied enormously in their power of resisting the wear and tear of time, and it is to this fact that North Wales and the Lake district owe the rugged grandeur of their scenery.

The depth and wide extent of the Ordovician sea is shown in many ways. We cannot here do more than briefly indicate a few of the reasons for the conclusion. In the first place we have the character of the materials. Apart from the volcanic masses already mentioned, Ordovician rocks are generally very fine grained, made up of thin beds



1 & 2. Radiolaria *(highly magnified)*.
3, 4 & 5. Foraminifera *(highly magnified)*.
6, 7 & 8. Graptolites *(two-thirds natural size)*.

and often partly limestone, which can only form in water sufficiently free from land derived material. Over very large areas the deposits consist of thin black shales full of the remains of a peculiar order of creatures known as Graptolites, and these are not infrequently associated with other animals called Trilobites.

Graptolites are so called from the fact that their fossil remains are always very thin and flat, looking more like things drawn upon the rock with a brush or pencil than included organisms. The whole order has long been extinct, but careful study of the best preserved fossils shows that they were Hydrozoons and probably lived in the ocean waters floating about attached to drifting weed, or perhaps to gelatinous floats similar to that of the modern Portuguese Man of War. Many of the same species occur in such widely separated regions as Sweden, Britain, France and Canada, and the beds in which they are found are themselves similar, facts which are difficult to explain on any other hypothesis than that of a widespread continuous ocean. It may easily be argued that as the order is extinct it is impossible to know what was their mode of life. But there are other facts.

The Trilobites are also an order of the past. They were very abundant during all Protozoic time, being the most characteristic feature of its fauna. They were strange animals not altogether unlike the modern King Crab in its earlier stages. One of them, found in the Cambrian rocks, was two feet or more in length. They were, as a rule, provided with well formed eyes, but, mingled with the Ordovician Graptolites, it is found that forms frequently occur in which the eyes are abnormally large, as if the creature lived in regions where the light was very feeble. In others eyes are altogether absent, as if the animals frequented waters too deep for light to penetrate. In short they were adapted to live in the darkness or dim light of the ocean depths.

An even more conclusive piece of evidence comes from the neighbouring county of Cornwall. In 1893 Mr. Howard Fox and Dr. Teall were investigating the structures of the Lizard peninsula when they found on Mullion Island a band of a hard

flinty rock called Chert which proved to contain vast numbers of fossil organisms called Radiolaria. The same band, or a similar one, has since been traced on the mainland associated with rocks which are pretty certainly of Ordovician age. Since then similar bands of Radiolarian Chert have been found interstratified with the thin black shales which are full of Graptolites, thereby proving beyond a possibility of doubt that they were formed under similar conditions and that those conditions reached so near to Devonshire as the end of Cornwall.

We have already hinted that the debris worn from a land surface and carried out into the sea comes to rest in a definite order. Nearest to the shore we get coarse shingle or rough broken material, further out comes sand, which gets finer and finer until we have a fine slimy mud. The coarser the material the thicker the deposit as a whole, until we come to a distance of a hundred miles or so from the coast, when the land derived material thins out to nothing. It has been found from the examination of samples of mud dredged up from the ocean floor that this land derived material, easily recognised under the microscope, is confined to a strip measuring from 100 to 300 miles in width, according to the strength of the currents bordering the continents and islands. Beyond this distance the mud consists generally of the skeletons and other hard parts of the creatures which dwell in the open sea.

Thus the North Atlantic is now paved with a pale grey slime, or ooze, which consists principally of the skeletons of minute animals called Foraminifera, a group of creatures whose bodies were stiffened with a framework of carbonate of lime dotted all over with tiny holes or foramina. They live in countless numbers in the waters and there must be a ceaseless gentle rain of their dead sinking slowly downwards. The protoplasm of their bodies soon decays and the little shells fall on. Now carbonate of lime dissolves in water which contains carbonic acid gas in solution, and the stronger the solution the more rapid will be the corrosion. All sea water contains some carbonic acid, but the greater the depth the larger is the percentage of gas, so that at very great depths any shell will be rapidly eaten away. The consequence is

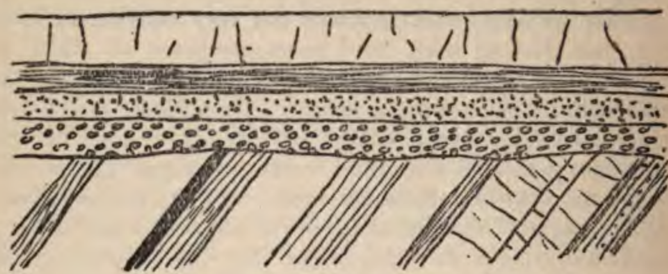
that a specimen of ooze from a moderate depth is found to contain abundant perfect and beautiful foraminiferal shells, principally those known as Globigerina, but as the depth increases the corrosion becomes more and more evident. Obviously we have only to go deeper and deeper until we must come to a stage when there will be nothing left. A rock, then, made largely of Foraminifera is almost certainly a deep sea deposit, but is equally certainly not an abysmal formation.

There are some other animals not very different in some ways, but having their hard parts composed of silica, or flinty matter, instead of carbonate of lime. These are the Radiolaria. They are much fewer in the surface waters than their calcareous contemporaries, but they live at all depths. The consequence is that the greater the abyss the heavier will be the rain of radiolarian tests. In the comparatively shallow regions the quantity of foraminiferal shells in a specimen of ooze is so much larger than the radiolarian that the latter are rarely seen, but as the depth increases they become relatively more and more frequent, until, if the ooze has come from about 3,000 fathoms or more it will be found that the insoluble siliceous skeletons have outlasted the soluble calcareous ones and the mud is almost exclusively of radiolarian origin.

Not many years ago it was frequently argued that no part of the existing land could ever have formed the floor of a really deep ocean, because we had nowhere found any rock resembling a radiolarian ooze in its composition. Hence it was maintained that the present arrangement of ocean and continent must in the main have endured ever since there was any division of the terrestrial surface into land and water. But the microscope has shown that the reasoning was based on false data. The dry land of to-day contains many layers of Radiolarian Chert, and the Mullion Island specimen is a sufficient answer in itself.

It is as well to point out that it is just possible that other causes might bring about a more rapid solution of the calcareous matter, and that a radiolarian ooze might accumulate in much shallower water than is possible now, but, if we couple the fact with the other reasons given, we cannot avoid

the conclusion that the Ordovician ocean at the time of its maximum was a great expanse comparable with the Atlantic, and that its waves rolled freely across the site of the Devonshire which was yet to be. The volcanic islands of Wales, Cumberland, and other spots lifted their summits above the water off the south-eastern shore of a great continent much



Unconformability.

Overlap.

as the Canary Isles or even the Azores now lie in the open ocean off the western coast of Africa.

The living things of Ordovician days were far more various than before. Around the shores and in the shallower parts of the sea floor banks and beds of shells accumulated and here and there where the conditions were suitable corals grew into reef-like masses which have been left to us as beds of limestone which tell the tale of their origin by their fossil contents.

Towards the close of the period the quiet and slow subsidence was converted into a movement of upheaval which was irregularly manifested. Here and there the sea bottom was

raised within reach of the wear and tear of waves or currents, or even into the open air. The old sediments were eroded and the muds and sands which marked the beginning of Silurian time therefore lie in such spots on the wasted edges of the older rocks. To use the orthodox term the Silurian beds are sometimes unconformable to the underlying Ordovician or even older rocks which had been laid bare by the complete removal of all Ordovician deposits. A considerable geographical change is here indicated. In the Welsh area sandstones, shales, and grits of evidently land derived material were followed by finer muds and extensive beds of limestone whose presence indicates periods of clearer water during which coral reefs could grow and piles of shells and coral fragments be heaped against them by the waves, where they have been solidified and now form beds of limestone like the crest of Wenlock Edge.

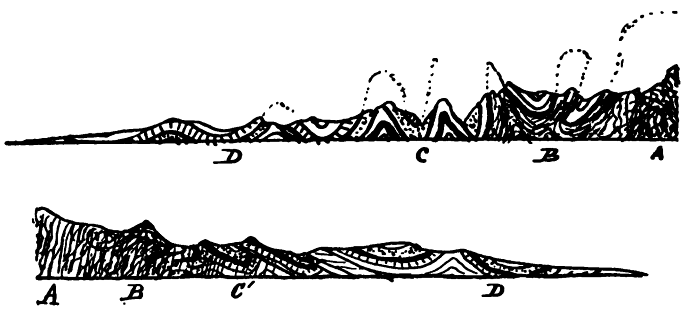
The evidence of the Silurian rocks points to a shallowing sea, to a steady advance of the coast line towards the south-east and finally to a great alteration of the map whereby the coast line was brought southwards to the middle of Scotland and Ireland. The stupendous forces which co-operate to make a mountain chain had set in.

As we shall meet with other examples of this vast operation it may be well to discuss its usual phases in a general way before dealing with the actual examples.

The chief cause of terrestrial convulsion is undoubtedly the slow cooling and consequent shrinkage of the internal portion of the globe. As the store of heat is diminished the interior shrinks, thereby throwing a tremendous strain upon the colder crust which has to fit itself to a smaller and smaller sphere. At first the strain is borne by the rigidity of the crust or partially relieved by a general subsidence during which its deeper seated portions are compressed and hardened. The result is the formation of a hollow which becomes the receptacle of material removed from the neighbouring lands, and the crust is steadily thickened. This deep covering of the older crust causes its temperature to rise and, owing partly to irregular loading, fissures are formed which become the outlets for volcanic action, the results of which are to fill the

cracks with solid wedges and to add to the loading of the crust.

As the internal shrinkage proceeds the overlying crust becomes more and more strained, until relief is found by some part of it giving way and either breaking into numberless slices which slide over one another or, more frequently, folding up into a complicated series of folds. It is evident that such relief will necessarily follow a series of lines at right angles to the direction of the greatest pressure, and will be more likely to take place where a great thickness of new soft rock has accumulated and the underlying old rock has been softened or weakened by heat, than in those places where the solid old rocks have been undisturbed.



Ideal Sections from the centre to the edge of a Mountain Chain.

A Rocks altered, original bedding destroyed.
B Rocks slightly altered, bedding obscure.
C Rocks unaltered, beds much bent.
C′ Rocks unaltered, beds much broken.
D Marginal gentle folds.

The result of the folding and puckering of the rocks or of their being piled up into a heap of fragments is to thicken them immensely. They cannot project downwards, therefore they bulge upwards, and the repeated folds make up a series of roughly parallel ranges traversing great distances.

If we study the detailed structure of such a region we find the folds broad and gentle on the flank, narrower and sharper as we proceed further until in the axis of the chain the confusion of the strata, once broad sheets of sediment on the

floor of the sea, is almost inconceivable to anyone who has not seen it.

At the close of the Silurian period this corner of the world experienced the first great mountain building throes of which we have any certain knowledge. The floor of the sea was raised into dry land, the Silurian, Ordovician, Cambrian, and Pre-Cambrian rocks were folded and crumpled, in some places so profoundly crushed and changed that they can no longer be identified, and a system of hill and mountain ranges brought into being. They extended through the Scandinavian peninsula, across the North Sea and Scotland, passed along the north-western shores of Ireland, and so away to some unknown distance along the southern shore of the North Atlantic Continent.

The Grampians, the mountains of Donegal and the southern uplands of Scotland are the ruined foundations of some of these ancient ranges, which have thus formed prominent features in British geography, as the Scandinavian range has formed a great feature of Europe, ever since the end of Protozoic time.

The building of modern Europe had begun and we reach the date when the history of Devon begins to be readable from its own records, when we can assign to it a place and character among its surroundings, not merely by induction, but from positive evidence supplied by things which may be seen by all who care to see.

CHAPTER II.

The Devonian Rocks of N. Devon.

The great movements which closed the Protozoic cycle resulted in a land surface which presented some very remarkable features in that part of the British area north of the Bristol Channel. Over extensive districts we meet with a great series of conglomerates, sandstones, and very impure limestones, nearly all of which are stained deeply with red oxide of iron, but here and there coloured less deeply in shades of yellow and even grey. These beds have long been known as the Old Red Sandstone.

Where the base of the system can be seen it is usually found that the upper part of the Silurian rocks are red in colour and that the bottom layers of the sandstone lie conformably upon them without any marked break in the succession. In other places the bottom beds lie on the denuded edges of older rocks and are obviously made up of the broken fragments of whatever underlies them.

The change from the finer materials of Silurian time is the result of the geographical change. The upheaval described in the last chapter ridged up the floor of the Silurian sea, shutting off portions into more or less land-locked lakes, or gulfs, into which were swept the debris of the intervening ridges.

The Old Red Sandstone everywhere abounds in proofs that its beds were accumulated close to shore, in shallow water and in reach of violent and variable currents. The thin beds or laminae composing the strata are very irregular, showing frequent examples of what is known as "false bedding" a structure always found in modern sands which have been deposited under such circumstances.

The pebbles which make up the conglomerates are often very large and very slightly waterworn as if they had formed parts of great sloping piles of rubbish fallen from the cliffs which had been rearranged roughly by the waves, or as if

they had been slowly accumulated in steep mountain valleys by the action of the weather and then hurriedly swept down by a violent torrent and piled in confusion over the floor of a lake or arm of the sea.

Here and there remains of plants have been found, especially in the south of Ireland where the slabs of sandstone are in certain places covered with the prints of magnificent fern fronds which cannot have drifted far from the spot on which they grew. In other cases sedge-like and grass-like markings have been found covering the surfaces as if the plants had grown not far away.

No shell fish of orders such as inhabit the open sea have been found in the Old Red Sandstone except in its topmost beds in the Welsh district, but in Ireland and other places a shell* has been found which strongly resembles the great freshwater mussel of our modern lakes and streams.

By far the most important fossils are the remains of great crustacea called Eurypterids, some of which were like cray fish, five and six feet long, and numerous fish of remarkable types which had their heads and bodies armoured with bony plates. These fish remains are unevenly scattered throughout the series. Sometimes a level is found at which the remains are thickly strewn over the rock surfaces as if some great catastrophe had caused the death of thousands and had then buried them before decomposition had set in.

Now the areas where Old Red Sandstone rocks are found are definitely marked and are separated by broad regions which we know from their rock structures were just those along which the Silurian sea floor was ridged up into ranges. The arrangement and nature of the coarser materials points to these ridges as their source, so that we should be prepared to learn that the basins were really distinct. If we bear in mind the indications of a freshwater origin, we at once begin to suspect that the basins were really great lakes.

The fish remains form an almost conclusive proof. If we form a set of collections from the different basins and compare the fish of one with those from another it is at once seen that

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* *Amnigenia (Anodonta) Jukesii.*

these basins cannot have been parts of an open sea. The differences are too great, and can only be satisfactorily explained by the theory of great lakes more or less completely separated.

We have already compared the Caledonian and Scandinavian chain with the Rocky Mountains or the Alps. We have here another point of similarity, for both these modern chains have passed through a stage when the hollows between their ranges were filled by sheets of water far larger than the present, which are but trifling pools on the floors of the ancient lakes.

So positive does the conclusion seem that Sir A. Geikie has given definite names to the different lakes. The most northern basin extends from the North Sea in a south-westerly direction on both sides of the Moray Firth. This he calls Lake Orcadie. South of the Grampian ridge came a long narrow sheet of water which reached across the central valley of Scotland and extended far into the north of Ireland. It is known as Lake Caledonia, and must have been a sheet of water comparable with the great lakes of Africa or America. Further south a large basin lay over the site of Hereford and extended from Shropshire in the north to Pembroke and the Mendip Hills in the south. It seems to have been less completely isolated than the northern basins and is known sometimes as the Welsh lake, or, from its possibly marine relations, the Welsh Gulf.

Kerry and Cork were the site of another freshwater lake called Lake Munster. A smaller region in the Cheviot Hills is called Lake Cheviot, and a smaller still, in Argyllshire, is known as Lake Lorne.

The sands and conglomerates of Lake Caledonia are interstratified with great flows of lava and coarse volcanic fragments which show that its shores were fringed with active volcanoes whose broken cones were washed by its waves and their materials spread out on the lake bottom. The volcanic phase appears to have been temporary only, and marked a time of earth movement when the lake basins experienced a further tilt so that the upper beds of the Old Red Sandstone series do not rest evenly on the lower.

Ideal restoration of Old Red Sandstone and Devonian Geography.

We are thus enabled to draw with considerable confidence a map of the British area north of the Bristol Channel and west of a line from Bristol to Berwick. East of this line the older rocks are hidden from view by much younger strata, and it is only where the Pre-Cambrian hills of Charnwood Forest peep up above the covering that we get a glimpse of an old land surface.

We can do more than mark the approximate boundaries of land and water. We can trace the lines along which the principal ranges lay and can even form a rough estimate of their importance by studying the amount of folding and compression their component rocks have undergone. The south-eastern ranges were of moderate extent when compared with those further north. Beyond Lake Caledonia the changes have gone far beyond mere crumpling. The rocks have been metamorphosed. Crystalline minerals have been produced, and structures are met with clearly indicative of the core of a considerable mountain mass. Beyond Lake Orcadie up in the north-western corner of Scotland the rocks, which include some of certainly Cambrian and Pre-Cambrian age, have been intersected by innumerable planes of fracture sloping gently to the south and east, and whole mountains have been made to slide up these planes for miles until the structures are probably the most complicated which have ever been unravelled.*

We shall certainly, then, be in small danger of error if we suppose the main chain lay over this north-western corner, and reached up to heights above the sea quite comparable with those attained by the great mountains of to-day. Lower and lower ranges lay between it and the sea, much like the way in which the Sierra Nevada and the coast ranges of California lie between the Rocky Mountains and the Pacific, while the dry basin of Utah is the equivalent of the area covered by the waters of Lake Caledonia.

In the map, the arrangement of land and water must be taken to be purely diagrammatic. We cannot at this distant date pretend to trace the shore lines with any detailed accuracy. Moreover, if we could do so for any

* See *Quart. Jour. Geol. Soc.*, 1888, page 378.

particular moment during the vast lapse of time covered by the period, it would be incorrect for even the next year. It is equally impossible to locate individual mountains or any valleys except the large ones, and quite beyond our power to trace the rivers. It is true that the outlets from which some of the lavas flowed can be identified, but no volcanic crater, no ridge or hollow of the time, can possibly have survived the wear and tear of the countless ages which have elapsed since they were first exposed to the wasting action of the air.

So far nothing has been said of Devon. Attention has been restricted to the country lying north of the Bristol Channel. The reason is simple—that the Old Red Sandstone extends no further south; its place in the geological sequence is there occupied by a totally different set of deposits which were most certainly marine.

Deposits of the same age as the Old Red Sandstone are found in two districts within the limits of Devonshire. The northern area extends southwards from the Bristol Channel to a line almost coincident with the railway from Taunton to Barnstaple, but generally a few hundred yards further south. At this boundary the beds of rock disappear under a newer series and do not reach the surface again until they rise up on both sides of Dartmoor, at Tavistock on the west and Chudleigh on the east. From these places to the English Channel by far the greater part of the country is covered by them.

In both districts the rocks have been greatly crushed and broken, so that it is comparatively seldom that we are able to find any fossils which are not more or less distorted, and in some places the original structure of the rock itself has been almost entirely destroyed by events which occurred considerably later on. In the extreme south of the county we have already said there are some crystalline metamorphic rocks making up the district round Salcombe and the Start which may be older, but which are just as probably of the same date as those immediately next to them.

The two series of deposits differ considerably, but the difference is not greater than we should expect to find in places whose distance from the shore of the old continent

varied by a space equal to the thirty miles which lie between them.

There are no similar rocks anywhere in the British Islands except in Cornwall, which is largely covered by a continuation of the southern series, and in the hills of West Somerset, whose structure resembles that of North Devon.

Having been first studied in Devon they received the name of Devonian Rocks and the period is therefore known all the world over as Devonian. We have already said that there is sufficient evidence to show that the Old Red Sandstone deposits were formed in lakes or land-locked basins, while the Devonian deposits were undoubtedly marine. Now when the structure of other parts of the world came to be explored it was found that the Devonian was really the world-wide, and that the Old Red is the local and exceptional variation.

The best way to examine these rocks and endeavour to interpret them is to confine attention to one of the two regions. To begin, then, with the northern exposure we will start at Lynmouth, where the great cliffs give us magnificent sections, and the deep gorges and rocky valleys enable us to see a great deal of the inland structure. Here there is a marked difference between the red beds of the Foreland and Countisbury and the grey and purple grey cliffs to the west of the harbour. The red rocks can be well studied at low water by walking along the beach and there are several sections in the roadside cuttings on the road to Watersmeet. The resemblance to the Old Red Sandstone deposits of the Welsh basin is so strong as to strike anyone who has seen both, but the colour is not as a rule so deep, the grey beds are much more numerous, the texture of the rock is generally much finer and here and there where small bands of fossils occur they are the remains of marine organisms.

At first sight the beds look as if they were very regularly stratified, though the strata have been greatly tilted and folded but a closer inspection reveals the fact that in many places the planes of division which look like bedding are really the result of pressure. In making the coach road to Watersmeet there are several places where the rock had to be removed by blasting

and these sections are well worth a careful scrutiny. The rock as a whole is very barren of fossils, but here and there rather wavy lines of irregular holes are to be found in the hard sandy stone. These lines run obliquely across the planes of division. A vigorous use of a hammer will soon show that the lines of holes are really little patches of fossils. The shells themselves have disappeared, and the cavities they once occupied have been more or less filled in with a red brown powder which crumbles at a touch.

Now if we walk over a sandy shore at low water everyone knows how usual it is to come upon little patches of shells left by the tide. We may walk for many yards without seeing one and then suddenly there are dozens in a square yard or so. Sometimes these patches lie in lines marking some pause in the tidal ebb or some local hollow in the sands. If we could clear away all that lies above one of the fossil bands we have been discussing there is no doubt we should lay bare just such a patch of shells, only they would be shells of Devonian time, and we should be looking on what was once the sea shore or the sea bottom close to shore.

As a rule the fossils are squeezed out of shape and the bands in which they lie do not coincide with the present planes of division. This, however, is a structure impressed at a later date and does not affect our interpretation of the conditions under which they were first formed.

The coarse grain of some of the beds, the irregularity of their internal structure here and there, and the mode of occurrence of the fossil shells all point to a shallow sea near shore, and the conclusion that these are the seaward continuation of the sands of the Welsh basin becomes irresistible.

If we turn from Lynmouth and go westwards either along the cliff paths or along the beach we find much finer grained materials and grey grits and sandstones which lie not much inclined from the horizontal. The grey grits are admirably shown in the Castle Rock and along the Valley of Rocks, while at the back of Lynton, in the Station Hill, there are a number of little quarries such as one in a lane known as Mount Sinai Lane where the beds are a very fine-grained shaly material of a dirty yellowish grey. These must have

been a finer mud settling to the bottom of the sea further from their source and not unlike the slimy muddy sand revealed at low water every here and there along the modern Bristol Channel. In the grey grits of the Castle Rock marine fossils are not rare, but they cannot very easily be found. A curious point about them is that they stand out on the surfaces which have been long exposed to the weather, and for a little distance into the stone they can be traced with sufficient care, but well within the interior the rock splits under the hammer and chisel without any regard to the fossils which may be there.

In the little quarry at Mount Sinai Lane the blocks of shale are easily split and the surfaces are often found to be covered with the traces of a marine hydrozoon *Fenestella* and with fragments of crinoids.

The curious castellated look of the Castle Rock and others in its vicinity is due solely to the facts that the beds lie nearly horizontal and the rock is naturally divided by cracks known as joint planes into roughly cubic blocks, and the blocks themselves vary a good deal in their power of resisting the wear and waste of time. The hills therefore tend to become rough piles of cubic blocks calling to mind the idea of ruined cyclopean masonry.

As we pass along the coast we find the beds of rock dipping down towards the west in Wooda Bay where they exhibit a great variety of texture. Some of these beds are fossiliferous, but the greater part are very barren. The rapid changes of texture point to variations in the power of the currents which brought down the material, such as might well be produced by changes in the ebb and flow of currents or an irregular sequence of rainy and drier seasons over the neighbouring land.

When we come to the great heights and magnificent cliff slopes of Trentishoe and the Great and Little Hangman hills we find another series of sandstones and grits strongly resembling those of the country east of Lynmouth. Are they another part of the same series of rocks, or does it mean that the conditions which gave rise to the Foreland deposits had been re-established? This is the first of the countless difficult

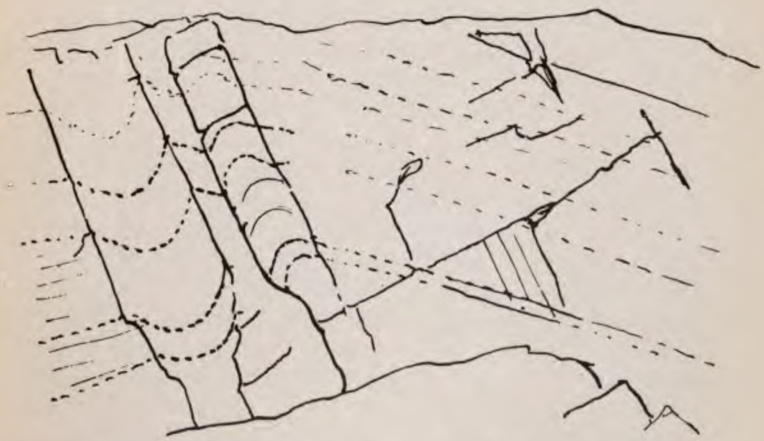
problems which we encounter. As we proceed we shall find many others, and it will be wisest to postpone any attempts to answer them until we are able to take a comprehensive view of them all. The cliff sections seem to indicate the return of the old conditions, but the proof is by no means conclusive.

After crossing Combmartin Bay we come to a series of rocks more like those we have already seen in Wooda Bay, a great series of shales which split into wavy flakes interspersed with thin bands of fine-grained sandstone, thicker layers of a soft slate-like rock, and here and there thin beds of limestone which thin out rapidly in all directions as if they had originally been lenticular patches on the sea floor. In most of these beds fossils are few and far between, but the limestones are in places made up of corals, crinoids, shells, and other organic remains. But here, as at the Castle Rock, the fossils can only be detected with difficulty in the interior of the stone. The difference of texture is so small that nothing but the slow and gentle solvent action of the weather can show them up properly. Almost all of them are more or less distorted.

To anyone who cares to try to unravel a greatly disturbed district, Ilfracombe and its neighbourhood is a paradise. Along the western face of Rillage Point the beds have been little crushed. They are tilted up at a high angle and near low water time, with a falling tide, they can be studied well. The paths to the beach are not very easy to find from above, but the section is well worth the trouble of scrambling down. When visiting the beach it is a wise precaution to have a companion who is not a keen geologist, but who may keep an eye upon the tide, as it comes in very rapidly and might easily pen an enthusiast in some recess from which there would be no escape without a swim.

Hillsborough again has a comparatively simple structure, though the great features of the cliff are due to the joint planes rather than the stratification. The Lantern Rock tells us a very different story. Viewed from the beach on its western side it is at first sight made up of a series of beds of rock rather highly inclined and dipping towards the south. But a closer inspection shows us that some of the apparent

Under the Torrs, Ilfracombe.



Key showing original bedding of Rock shown above.

Under the Torrs, Ilfracombe.

Key showing original bedding of Rock shown above.

beds are nothing of the kind. The original stratification has been almost destroyed. The soft shales have been crumpled up into a confused mass which has been sheared across by crack upon crack and it is these cracks which simulate the bedding.

The Capstone hill affords another example of subsequent disturbance. On its western face the original strata are boldly shown by the thin sandstone beds which are interspersed among the shales. The latter split up along planes more highly inclined, and, if it were not for the sandstones, these cleavage planes would almost certainly have been taken to represent the planes of deposit instead of a totally different structure, namely cleavage induced by pressure.

Perhaps the best examples of these changes are to be found in the neighbourhood of the Torrs Walks, on the beach beneath them and in the road cuttings behind.

Some distance along the Walks there is a path which leads down some steps to the beach. These steps are cut down a low cliff in which the bedding is at first sight very plainly shown, but careful study shows that the surfaces of the rock are traversed by wavy bands in shades of grey and brownish grey. These are the original beds, and the other apparent beds are only planes of division caused by a shearing action.

The correctness of this view is very plainly shown in a large rock on the opposite side of the cove, where the true bedding is betrayed by a thin band of sandstone, the hardness of which has enabled it to resist deforming forces which profoundly affected the softer shales.

The same thing is shown again in the road behind the Torrs. There a cutting shows dark grey shales apparently inclined in one direction. But some height above the road they are crossed obliquely by a series of whitish bands greatly puckered and copying each other's folds in such a manner that they can only be the old rock bedding.

Similar structures are found here and there as we go on towards Lee Valley and Morthoe, but the materials of which the rocks are made become finer and finer. Sandstones disappear, limestones are fewer and further between, until at Morte Point and along a belt of country extending eastwards

through the Station Hill at Ilfracombe we find pale grey slates which must have been originally fine clay mud very much like some of the grey muds of the Silurian Sea. The forces which distorted the Lynton fossils, and which obscured the bedding of the rocks round Ilfracombe, have here acted with far greater intensity, and the original bedding has been almost entirely destroyed and its place taken by a slaty cleavage which causes the rock to split along almost vertical planes. For a long time these slates were supposed to contain no fossils, but Dr. Hicks in the year 1890 found a considerable number in various spots. One of the most prolific is a small quarry at Mullacott, on the road which leads inland past Ilfracombe Station. Some distance up the long hill there are two little quarries; the southern one now contains the town dust destructor and the smaller northern excavation is partly filled in with old scrap iron, lobster tins, and similar unsavoury waste which is presumably incombustible. Up in the western corner of this unlikely looking spot the planes of cleavage happen to coincide with the bedding, and fossils will almost certainly reward an hour's industry. The slates have to be split open with the sharp edge of a hammer. They themselves are sharp and fairly hard, so that thick gloves are very desirable.

In another quarry across the valley the slates are covered with curious markings which Dr. Hicks claimed to be graptolites, but the general belief is that they are only markings produced by the infiltration and deposit of mineral substances between the slates.

The original bedding can be detected with difficulty here and there. The best way to see it is to choose a time when it is low water at spring tides and walk out on the sands by the water's edge just below the newer part of Morthoe. Then if the light is favourable the contorted bedding may be seen as bands of shading cutting most irregularly across the edges of the slates. The beds have been folded over and over again so that the tangle is impossible to unravel. It is best seen when the sun is in the west so that there are little or no shadows since the jagged slates stand out as a series of great saws projecting westwards.

Morte Slates showing traces of stratification.

West face of the Lantern Rock, Ilfracombe.

We have seen that the Ilfracombe beds are, on the whole, made of finer materials than those previously described, finer than the shales of Lynton and Wooda Bay, and much finer than the Hangman and Foreland grits. This should mean greater distance from the shore, or from the source of the sediments, or the arise of some obstacle so that the finer material came to rest after the coarser had fallen to the bottom. The original mud must have been deposited in moderately deep water, and the limestone patches point to rather long periods during which the water was clear enough for corals to begin to grow on shell banks, but before they had built up any considerable reefs an influx of muddy water overwhelmed them time after time.

Continuing our exploration of the coast we cross the long stretch of Woolacombe Sands where the low cliff is composed of a series of sandy rocks called the Pickwell Down Sandstone, but it is unfortunately buried under a pile of blown sand heaped up against it by the western gales. On reaching the bold slopes of Baggy point, we find purple and red coarse-grained sands known as the Marwood beds. Beds of fossils occur and there is every indication of shallow water and either a near shore or strong currents. Indeed the conditions indicated by the Hangman and Lynton beds are to a large extent repeated. If we follow the shore round into Croyde Bay and on to Braunton we find a sequence of rocks very like that of Wooda Bay and Lynmouth, sandstones and hardened shales interspersed with bands crowded with fossils resembling in their general appearance those from the northern rocks, but of different species. These are known as the Marwood and Pilton beds. This last series is not so much disturbed as the Morte slates or the Ilfracombe rocks, but the evidences of compression are again more like those seen at Lynton. The fossils are almost always distorted. The beds are often highly inclined, dipping southwards at a high angle and their surfaces where laid bare along the coast are often marked with a waved structure which may be ripple marks like those upon a modern sandy bottom, or on the other hand may with equal probability be a pucker structure resulting from great pressure.

We have, so far, avoided the question of the order in which these different groups of rocks were deposited, the order of superposition. Unfortunately the coast section is not complete. It is broken here and there so that we cannot be certain whether one group is the true continuation of another or whether the groups owe their apparent succession to a series of great fractures, or faults, between which the groups stand at different levels.

There are, in fact, two totally diverse views of the North Devon succession. It was formerly supposed that the Foreland grits were the oldest, and that they were overlaid in turn by the Lynton beds, Hangman grits, Ilfracombe beds, Morte slates, Pickwell Down sands, Marwood beds and Pilton beds. According to this view we can explain the sequence of rocks by supposing that the Foreland grits were the seaward extension of the Lower Old Red Sandstone of the Welsh basin, that the sea then deepened, or that the currents slackened for a time, or that a barrier arose shutting off the Welsh basin, and that the original conditions were soon re-established. Again the sea deepened and the coast line retreated or the currents slackened more and more until the fairly deep sea indicated by the Morte slates was attained. Then, rather suddenly, the old arrangements were once more produced and the sands of Baggy Point laid down. But the lapse of time had been considerable and the species of shells had been changed, so that the newer sands had different inhabitants. There is no impossibility in these suppositions, but it is not easy to account for the much greater symptoms of compression in the Ilfracombe and Morte beds than in the rocks on either side, and such considerable changes in geographical conditions seem rather improbable. Moreover it seems certain that the earlier investigators to whom this explanation is due did not fully understand how profoundly the structure of some of these districts had been altered. It seems that they probably mistook for true stratification some of the planes of division which have been pointed out to be really planes of shearing, the result of great earth pressures, and almost obliterating the original stratification.

So strongly were these difficulties felt, coupled with another which will be described further on, that in 1896 Dr. Hicks published an entirely different theory.*

It has been mentioned that he found fossils in the Morte slates which had previously been supposed to be barren. We have also referred to the resemblance between these rocks and some Silurian beds. He announced his belief that they were actually of Silurian age and that the sequence in the district was really—Morte slates of Silurian age, and then the Ilfracombe beds of lower Old Red Sandstone time, while the sands and grits of Lynton and the Hangman Hills were of the same age as the sands and grits of the more southern district. He believed that the divisions between the groups were probably faults.

The identification of the Morte slates as Silurian appears to rest on insufficient data. The fossils found seem to be of peculiar species, and none have been certainly shown to agree with those from undoubted Silurian rocks. But, however this may be, it is quite possible that his view may be correct in so far as the relative age of the groups is concerned. If he is, the sequence of geographical events would be as follows:—The Morte slates and Ilfracombe beds would be the marine deposits forming in a sea separated from the Welsh Lake by some barrier which prevented the coarse detritus from the land from spreading beyond its boundaries. The lake may have acted as a great settling tank, keeping the neighbouring sea comparatively clear, so that only the finest mud could reach the deeper water. As time went on the great basin became partly filled and probably the barrier became wasted by erosion until at length it was destroyed or overwhelmed, or the lake filled up and the sand-laden rushing rivers carried their burden freely into the open sea where it was spread further and further. The difference in the shells of the two districts is no more than might fairly be expected on a shelving bottom in a distance of fifteen or twenty miles.

This is a simpler hypothesis than the other, and one more in accordance with our experience of such phenomena at

* *Quart. Jour. Geol. Soc.*, 1896, p. 254.

other times and in other places. The changes required are progressive, and indeed they are such as we know must most probably have occurred in the absence of earth movements such as would have been almost certain to have left their traces in the Old Red Sandstone region on the other shore of the Bristol Channel.

The structures due to pressure were created at a later date and do not affect the question in hand.

It can only be settled by further work. It may be possible on the one hand to correlate the North Devon beds more positively with those of South Devon and the Continent by means of their included fossils, and local geologists by diligently recording every section in careful detail may bridge over the gaps in the succession and show that the apparent order of superposition is the true sequence. On the other hand a greater number of better fossils may result in proving that the northern sands and grits are really represented by the southern, and the great faults which Dr. Hicks suggests may be found to be actual fact. Finally it may be shown that the whole North Devon structure is that of a single folded ridge, folded so strongly as to crumple and fracture all the beds and produce the structures we see, but essentially consisting of a single or repeated arch with the system of grits the newest and the fine grained slates of Morte the oldest.

CHAPTER III.

The South Devon Rocks.

The rocks of South Devon are much more diversified than the northern rocks which we have just described. They lie in much greater confusion than even the Ilfracombe beds, though it is doubtful whether there is anything in South Devon quite comparable with some of the structures already mentioned as affecting the district of Morthoe. The beds are almost always highly inclined and in many places they have been actually overturned, so that the apparent order of superposition is the reverse of the true succession. Sharp curves and acute folds are quite common, and as we move further and further south these symptoms of intense compression become more and more pronounced.

The great bulk of the strata consist of soft slates and shales with sandy beds of harder rock, all of which resemble strongly the deposits already seen at Wooda Bay and Ilfracombe. They are made of sands, grits and muds which can only be the results of weather action on some land mass, and on the whole they represent types of sediments which would probably come to rest further away from the source of origin than the corresponding rocks of the Exmoor area. They are, however, mixed with very important masses of material which had a local origin, namely, the limestones which form almost the most conspicuous feature in the scenery, and a great series of volcanic formations which are spread as a string of patches from Newton Abbot southwards to Totnes. South of this town they swell out into a wider expanse, which seems to mark one of the chief centres of activity. The village of Ashprington lies south of its centre, hence when they were described in detail by Mr. Champernowne he named them the Ashprington Volcanic Series.* The valley of the Dart from Totnes to Dittisham is cut through a complicated pile of

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* *Quart. Jour. Geol. Soc.*, 1889, p. 369.

very diverse volcanic material, and the bold scenery, with its characteristic steep wooded hills intersected with deep valleys, is due to their different powers of resisting erosion.

The same, or similar, eruptive materials appear again and again at Ugborough and Modbury and between Yealmpton and Plymouth. They then spread into Cornwall, a few exposures making their appearance near Saltash, St. Germans, Liskeard, and Callington, which connect the South Devon series with another which is largely developed around the north-eastern and north-western sides of the granitic boss of Brown Willy and Bodmin Moor. A few lavas and patches of hardened ash occur further west, but their relation to the Devonian exposures is less obvious.

The Limestones, which are intimately related to the products of eruptive activity are practically restricted to the Devonshire district. It will be remembered that one characteristic of the Ilfracombe beds was the frequent appearance of lenticular patches of limestone, crowded with fossils and thinning out rapidly in all directions. These were attributed to temporary pauses in the deposit of mud which allowed a certain amount of coralline and shelly material to accumulate. The pauses were never long, and each patch was overwhelmed by an influx of mud before it had time to grow to a thickness of more than a few inches or a foot or two.

In South Devon the contrast is very great. The limestones of Torquay, Brixham, and Plymouth Hoe are hundreds of feet in thickness and extend horizontally in some cases for several miles; the Brixham mass, for example, stretches without a break from a point on the Dart north of Galmpton Ferry to Berry Head, a distance of more than four miles from east to west, while its width from north to south is rather more than a mile.

But such masses are the exception. Not only are the rocks of the whole area folded and crumpled, but they are broken across by repeated fractures, or faults, which slope downwards into the earth at all sorts of angles. Sometimes we find the fracture vertical and on one side a mass of limestone, on the other slate or grit, or a rock of volcanic origin.

Sometimes the line of division is inclined but little from the horizontal and we can see how one kind of substance has been pushed bodily over another. All the rocks of the district are similarly disturbed.

Still more, some of the volcanic beds lie in sheets and were evidently piled on top of the underlying stone either as a flow of lava spreading over the sea bottom as it welled out from some neighbouring fissure, or as a rain of volcanic mud settling down to the floor of the sea as it fell from the dust cloud produced by a violent eruption. These then are interstratified among the other rocks.

But when a volcano is active the lava does not always escape from the summit, or from an open fissure. The relief is frequently gained by the molten flood forcing its way between beds of solid rock underground. In such a case the strata may give way along the division between two beds, when the lava will lie as a sheet in very much the same way as if it had been poured out during the interval between their deposition, instead of being injected at some unknown date after they had both been formed.

Now a lava which is actually erupted on dry land or on the sea bottom always contains more or less water under great pressure, and on reaching the surface, even under water, this pressure is lessened, so that bubbles of steam make their appearance and blow out the viscid cooling rock into a more or less frothy texture. Moreover the process of cooling is comparatively rapid, and, unless some of the component minerals have already crystallised before eruption, the cold mass will contain no large crystals, and such as there are will be held in a much finer grained or even glassy matrix.

Suppose, on the other hand, the rock to have been injected between two already solid beds. The weight of the superincumbent mass will prevent the formation of steam bubbles, so that the spongy texture cannot be assumed, and the overlying rock, being a poor conductor of heat, will cause the process of cooling to be greatly prolonged, so that the diverse minerals will have more time to form. Coarser and more uniform crystals will be the result.

The volcanic rock thus contains its own certificate of the conditions under which it solidified, and an injected sheet is known technically as a sill.

There are other tests which can be applied if there is any ambiguity about the rock itself. When a lava stream flows over some other rock, this underlying material is baked and more or less hardened and altered by the great heat. As the lava cools, great cracks are formed in its rough and irregular upper surface, and when the subsequent deposits fall upon it they penetrate these cracks and, of course, show no signs of baking or alteration.

An injected sill, on the contrary, bakes and alters both the beds below it and the beds above it, and, so far from being penetrated by either, it commonly sends off branches of its own substance into them, or even breaks irregularly across them wherever they chance to have been fractured.

Injected volcanic material is by no means always confined, even in part of its course, to the planes dividing one stratum from another. Sills are the exception rather than the rule. Far more frequently the molten material breaks quite irregularly across bed after bed, paying little or no regard to the original divisional planes. It is then said simply to be intrusive.

All these phenomena are exemplified again and again in South Devon. Some of the volcanic rocks are clearly interstratified with the slates and limestones. These at least must have been the products of eruptions which took place from time to time during the same period. They must, as we say, have been contemporaneous with those slates and limestones.

Where they are intrusive, either as sills, or as filling cross and branching fractures, we cannot be certain of their exact age, except that the eruptive forces which injected them were exerted at some date later than that at which the slates [and limestones were laid down. It is possible, then, that some of the volcanic rocks intrusive into the southern Devonian formations may really belong to a later date, and, as we shall see in the sequel, this is fully probable.

There are hundreds of examples of volcanic rock in Devon, and, of the whole, only a minor fraction have yet been studied

in full detail. When all have passed under the careful scrutiny of experts it may be possible to identify those of Devonian age and separate out those (probably fewer) which really belong to a later period. In a given volcanic region it is usually found that the products of the earlier eruptions differ in chemical composition, and therefore in the minerals they contain, from those of the later phases of activity. We know well that the Devonian volcanoes were continued into a much later time, and it is possible that some sequence of composition may be revealed which will give us the clue by which the newer rocks may be distinguished from the older.

If the sedimentary rocks, the grits, shales, slates and limestones were spread out in widely extended sheets and contained numerous well preserved fossils it would be easy enough to write the history of the time. But the facts are far otherwise. Great earth movements have broken up the district and piled the parts irregularly together, crushing, distorting and even destroying the fossils, so that there are considerable areas whose proper place in Devonian time can only be guessed quite roughly by the general colour and texture of the deposit.

It has been said that the results of compression become more marked as we pass southward. As we do so, the wavy surfaces of the flakes and slabs into which the shales and slates weather become dotted with glistening flakes of various minerals. At first the original character of the rock can be plainly seen, and the new minerals only appear as spots and streaks upon the planes of cleavage. But the folding and signs of pressure increase southward, till, when we pass a line running east and west from Tor Cross through Kingsbridge to the mouth of the Avon we meet with beds of quite uncertain age, which extend over a belt of country about two miles wide and reaching from sea to sea. On the southern limit of this belt the strata suddenly become true crystalline schists, or rocks more or less completely crystalline and composed of wavy layers of different minerals. Some of them were almost certainly originally shales or slates, others were either sills or lavas, but their minerals have been rearranged so as to assume the same structure in wavy layers.

These are the rocks which some consider to be altered representatives of deposits formed in Protozoic or even Pre-Cambrian time. Others consider that they are only Devonian rocks much more highly altered than their neighbours It is quite certain that they could have been produced by metamorphic action on a series of Devonian strata, but if such they are, we should have expected to find the metamorphic changes shading gradually upwards from those shown to the north of the line until they reached their full intensity, and not suddenly jumping from a quite early stage in the re-crystallization to the fully developed crystalline schist. The boundary may well be a fault, and these enigmatical rocks may be only a deeper seated part of the Devonian system brought up along the line of fissure, just as we know the lower beds lie in juxtaposition with the upper in the neigbourhood of Torquay and Paignton. The metamorphism displayed in them is exactly such as would be produced by lateral compression under a sufficient vertical pressure, and such as we find produced in rocks of all ages which have been exposed to adequate causes.

Some of these schistose rocks, which were originally volcanic, are coloured a vivid green, especally striking when they are wetted by the waves. Others are various shades of grey, and fresh surfaces glitter with spangles of mica and crystals of quartz. They are all of them often penetrated with branching veins of white quartz.

They can be well studied along the coast from Hallsands to the Start, and around the Bolt Head. In the latter district they are cut up by a series of contortions which help to determine the features of the cliff.

So far, although we have had occasion to refer to differences in age within the Devonian rocks of South Devon, we have avoided any attempt to describe their succession in time. North Devon presented a difficult problem, but the much greater complexity of the structure of the southern area makes the problem at first sight far more hard to solve. Indeed as long as geologists had only local evidences to rely upon the task was impossible. Fifty years had elapsed since the Devonian system had been made known to science

by the work of Englishmen in Devon, before it became possible to unravel the tangle. De la Beche, Godwin-Austen, Holl and Champernowne each attempted the task in vain, though each contributed something, especially the last named. It was reserved for Mr. W. A. E. Ussher to find the true key and apply it successfully, and even his work is not yet complete.

It has been pointed out, in the last chapter, that the Devonian type is widespread. As a matter of fact rocks of this age and character are found in France, Belgium, Germany, Russia, and in North America, over all of which the waves of the Devonian ocean rolled. In these regions the sediments formed on the sea floor have been comparatively little disturbed. Their fossils are well preserved and the true order of superposition of the strata can be easily read.

By studying these deposits it becomes a simple matter to arrange the fossils in the order in which they appeared, and it is seen that certain organisms were widely disseminated and followed each other in the same order wherever they were found.

When this test is applied to the rocks of Devon we find that the local fossils are frequently abundant enough to justify definite conclusions as to whether they belong to the lower, middle, or upper beds of the system, and if we can so locate one bed, that gives us a clue to the position of many others with which it happens to be associated. There are wide areas over which no fossils have yet been found sufficiently well preserved to admit of identification, so that we can there only rely on the general character of the beds by comparing them with other similar rocks whose approximate age we can determine more certainly.

Broadly speaking, the lower division is characterised by the occurrence of sandstones and grits and the absence of volcanic constituents. Though this is generally true, the coarse sediments shade upwards irregularly into finer grained shales and slates which merge quite insensibly into the lower strata of the middle division. It is thus evident the coast line from which the coarse material came must

have receded, or that the rivers must have slackened. The process was not sudden, but steadily progressive during lower Devonian time, and the same conditions continued into the earlier part of the period in which the middle Devonian beds were laid down.

These middle beds consist at first of grey and bluish slates with occasional thin patches of fossils. They are overlaid by shaly limestones, generally dark grey in colour from the contained impurities, which are in turn covered by more massive limestones, paler in colour, and in some places practically built up of corals.

The massive beds lead up to the upper Devonian division. This consists of thinner bedded limestones which are often coloured red or purple red, and these alternate with chocolate coloured slates and mudstones which become pale lilac in tint after exposure to the weather. The limestones are generally very compact, and often of lumpy or concretionary structure. They are overlaid by red and greenish slates which pass upwards into deposits belonging to the next great geological epoch.

Lower Devonian rocks form the sands, slates, and grits of the Torquay peninsula, where they may be easily studied in the neighbourhood of Meadfoot sands and Warberry Hill. They also cover a considerable area to the north and west of Paignton, where they crop out from under the much newer deposits on which the town is built. Passing on along the coast, they form Southdown Cliff and extend thence in a series of bands of variable breadth across to Plymouth Sound.

According to Mr. Ussher the Middle Devonian strata comprise, first, the Eifelian slates and shaly limestones, so-called from their representatives in the district of the Eifel. Secondly, the Ashprington volcanic series which is partly, at least, contemporaneous with the massive grey Middle Devonian limestones. The volcanic rocks can be found in numerous places. The widest expanse is between Totnes and Ashprington on either side of the Dart. Here is a district of between nine and ten square miles entirely composed of consolidated tuffs, and penetrated by lavas and

injected igneous materials. But they are by no means restricted to this region. Pipes, veins, and sheets of molten rock have penetrated the shaly and slaty beds west and south-west of Newton Abbot in numberless places. Indeed this volcanic district extends from Kingsteignton through Newton Abbot in a great sweep round the south-eastern corner of Dartmoor, by way of Totnes and Ashprington, whence it is continued westwards as a band of variable width, bounded by Eifelian slates, till it reaches Plymouth Sound, whence it spreads far into Cornwall. Throughout this extensive area the volcanic rocks are predominant, but they come up as sheets, sills, and intrusive veins in many other places, such as the cliffs of Babbacombe, the shore of Anstey's small Cove, and the neighbourhood of Dartmouth and Stoke Fleming.

The limestones are a connecting link between Middle and Upper Devonian time. In the survey map no distinction is made between those which belong to each division. In many cases well preserved corals are abundant in them, and here and there, as at Barton, Lummaton, and Petit Tor, the rock is composed of corals having a structure well shown in some of the so-called Devonshire Marbles whose "figure" is due to the coralline composition.

From bottom to top of the whole series we have clear evidence of marine conditions. We also find that if we except the volcanic accumulations the materials are fine, such as would have come to rest on the sea bottom some distance from shore. The individual beds of sediment are also thin, a fact which again indicates slow accumulation.

The tuffs and volcanic ashes are often regularly stratified and their materials constant for some distance, which indicates the settlement of dust through the water rather than the actual building up of a volcanic island. Other sections, however, indicate a different structure, and we cannot be far wrong in concluding that a chain of volcanic islets and submarine volcanoes extended in long lines from the Ashprington patch northwards and westwards.

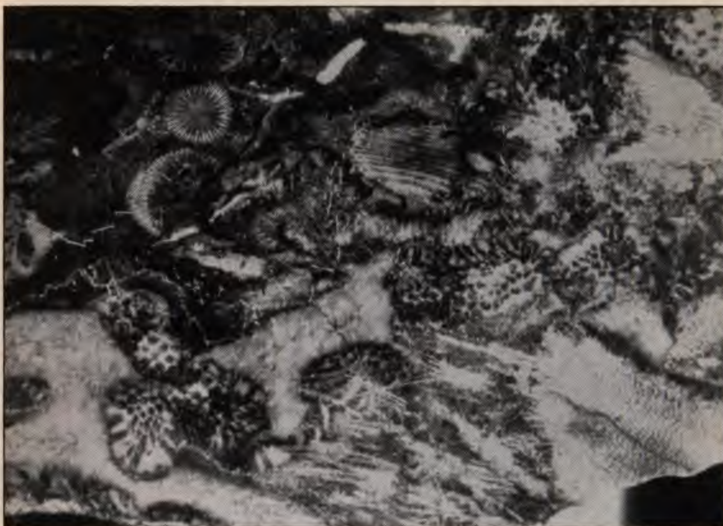
The limestones are of two kinds, those where the beds of calcareous material are thin and are interspersed with shales. In this case we must regard them as having been formed during times when there was little mud either from the distant land or from the neighbouring volcanic shores, by the accumulation of organic debris from the creatures living in the water or on these islands. Next, there are the massive beds made up here and there of corals. These we cannot hesitate to identify as coral reefs which grew up around the shores, or on the shoals around the volcanic cones which must have been thickly strewn over the district.

Coral reefs, whether fringing reefs, or any other type have been shown to contain but little indications of their coralline origin. From the interior of a modern coral island, limestone is raised which contains no more numerous traces of its origin than any of the South Devon stone. The narrow crevices of the reef building corals get filled in with calcareous fragments and mud, and, in time, the whole becomes thoroughly welded together. Here and there the structure is preserved, and it is beautifully shown in many parts of Devon.

The history, then, of Devonian time, as it may be read from the rocks of South Devon, is briefly thus:—

We begin with an open sea extending from the North Devon district to Brittany, reaching to an unknown distance westwards, and extending eastwards through the centre of what is now Europe.

It will be remembered that the south of Wales was the site of one great lake, separated from North Devon by an imperfect barrier, while another large sheet of water, which was almost undoubtedly fresh, lay over the extreme South of Ireland. This was most probably cut off completely from the sea. The rocks of Cornwall on the other hand are of the same type as those we have been describing, except that they do not contain the same great development of limestone. It seems, then, that the nearest coast line of the north-western continent must have lain somewhere along the middle of St. George's Channel.



Section of Devonian Limestone.

Wavy structure and shear plane, near Kingsbridge.

Rivers, no doubt, flowed into the sea, and brought with them from the land detritus, which was strewn far and wide over the sea floor. Hence the grits and gritty slates of Lower Devonian time. But, as the slope of the rivers decreased as the land became worn away, they carried finer mud, and after a time it was only occasionally that any large quantity of it was borne so far as the district we have described.

Beds of limestone now began to form, at first thin and inextensive like those of Ilfracombe, but later on more and more massive.

But simultaneously with the clearing of the water from the muds of the continent, a chain of volcanic centres began to show symptoms of activity. It began with the formation of shallows on the sea floor, which grew into islands, while, in the periods of repose, corals took root upon them and built up fringing reefs and barrier reefs extending outwards into deeper water on the top of piles of broken coral torn from their own upper portions.

Again and again, new floods of lavas were erupted, and the molten rock in seeking an outlet forced its way through the slates and limestones, forming the veins and pipes and sills of igneous rock so often seen.

The volcanoes, however, like most of our modern volcanoes situated on islets, frequently gave rise to explosive outbursts, when clouds of steam carried with them vast quantities of volcanic dust and debris which fell to the bottom of the sea, killing the corals and entombing many of the creatures which crawled over the muddy bottom.

As the volcanoes grew, rain falling on their sides carried down mud and sand into the sea, and the luxuriant growth of corals came to an end, their ancient homes being covered with mud, which is now solidified into the slates which are generally regarded as forming the latest of all the long series of deposits, which are grouped under the name of the Devonian Rocks.

We can thus close our attempt to reconstruct the geography of Old Red Sandstone and Devonian times by picturing a coast line roughly coincident with the Bristol

Channel and extending far westwards some distance south of Ireland. North of this line a vast continent, fringed on its south-east border by a great mountain chain whose parallel ridges cut up the region into a number of basins, some of which were occupied by great freshwater lakes. One of these on the borders of Wales was shut off from the open ocean by a chain of islands like the Zuyder Zee, or as the Sea of Japan, at present, is cut off from the Pacific.

Off the shores of this continent was the sea dotted with an archipelago of volcanic islets, fringed with reefs and banks of coral over the site of Devon, but curiously enough we cannot say exactly where either the islands or the coast line were. It has been repeatedly said that all the Devonshire rocks show proofs of enormous crushing, crumpling and folding. We must allow for this in our attempted reconstruction, and imagine these deposits spread out in some such layers as they were when first formed. We shall then find that the North and South Devon beds must have been many miles further apart than we find them to-day. If it were possible to trace out all the folds and contortions, and if it were possible to measure the distances along which each block of rocks has been pushed over its neighbours, we might construct a map showing the ancient reefs, and locating some of the chief centres of eruption. In the absence of the necessary knowledge, we must be content with the general facts, and regard the coral islets as having stood where we now find their ruins. The general dimensions also of the archipelago must not be estimated from what we see to-day. We must remember that they may have extended a long way further east and south where now lie the waters of the English Channel.

It is possible also that where the lower Devonian beds now come to the surface, they may have been covered with deposits like those of Brixham or Ashprington, so that the same conditions may have extended further south and west. This we can never know, so that however much the rocks of Devon may be studied, and however much we may add to our own present knowledge of them, we can never hope to know all their story.

CHAPTER IV.

The Culm of Devon.

At length the great continent began to subside, and the water of the open sea flowed up the valleys, filling the basins of the great lakes as far as the Grampian ridge and spreading over the lower lying parts of the former land. The disappearance of the ancient Pre-Cambrian country was repeated once more, but this second sinking was less complete.

Everywhere where the top of the Old Red Sandstone or Devonian rocks can be seen their topmost beds are seen to shade upwards into a series of sands and shales containing some of the same organisms mixed with a number of new forms which are undoubtedly marine. There was no sudden break either in the life of the region or in the geography, but the change in the distribution of land and water was progressive, and a similar alteration was produced in their inhabitants.

The lower beds of the new series are composed of land derived material, and, as the thickness of a group of deposits of a given kind is a rough indication of the length of time during which they were formed, it seems that the sinking of the old land must have been rapid. The sands and shales are seldom more than a couple of hundred feet in thickness, over all the great district from the old coast line south of Bristol across the central parts of England and Ireland until we approach the basin of Lake Caledonia and the neighbourhood of the Cheviot and Cumbrian Mountains in the north.

Over all the central parts of England and Ireland the basement beds are covered with a vast deposit of limestone which contains numberless traces of its organic origin. Corals, shells, crinoids and other creatures have contributed largely to its production. It has long been known as the Carboniferous or Mountain Limestone. It is a fairly pure

carbonate of lime containing very little earthy impurity such as might have been borne from a distant shore, and must have taken an immense time to form. In places it is more than 3000 feet in thickness, the maximum being reached in the Mendip Hills, which form almost its most southern outcrop. It is interspersed with layers and patches of chert formed chiefly from the siliceous sponges and organisms originally mixed with the calcareous mud, but subsquently gathered together by the obscure process called segregation. The whole deposit must certainly have been formed in a sea singularly free from land derived material, so that if any shore lines came nearer than a hundred miles, those shores must have been made of hard rocks and cannot have had any rivers or streams bearing mud into the sea.

As we pass northwards we find the limestone somewhat thinner, and in the North of England it becomes more and more broken up by the interposition of beds of sand and shales and even coal, until in Northumberland the whole series indicates that shores of some extent were not far away. The limestone still exists, but the periods when it was allowed to form were frequently interrupted by times when the sea had a sandy bottom.

On crossing the border and entering the basin of Lake Caledonia we find the whole deposit from bottom to top indicative of shallow water and abundant influx of land derived debris. The limestones are only thin lenticular beds, while every here and there occur coal seams and layers of ironstone.

We cannot here enter into a discussion as to the origin of coal. It is the general belief that most of our coal seams are an accumulation of vegetable matter formed from plants which grew where the coal now lies, at a time when the clay, so often found beneath, was the soil of a swampy forest. The coal plants were mainly analogous to our mares' tails, club mosses, and other spore producing plants, and it is believed that the regions where they flourished in greatest luxuriance were level plains, sometimes partly occupied by fresh water lagoons, sometimes intersected by sluggish rivers, and all liable from

time to time, as subsidence progressed, to be overwhelmed by an influx of the sea.

Here and there the coal was probably formed from vegetable matter drifted from a distance, and some seams may have been locally produced from deposits of resinous spores.

On the whole it is safe to say that the occurrence of coal seams points to shore lagoon swamps, and a succession of seams with their interveining sandstones we shall speak of as the shore lagoon type of strata.

In Ireland the changes are similar in character, and the shore lagoon type shows signs of setting in as we approach the site of the southern end of the great lake.

There is another peculiarity in the South of Ireland. Here there are many indications of shores lying not much further south or west, a point which will be seen to have an importance in the history of Devon.

Jukes-Brown has shewn* that there is reason to think that a large island lay over part of the English Midlands, and extended through Wales to the Wicklow Mountains and the Mourne Mountains.

It is not easy to reconcile this with the purity of the Carboniferous Limestone all round it except on its northern side. It seems more likely that as the continent subsided the Cumbrian and Cambrian Mountains and the Wicklow and Mourne heights, all of which were, in Devonian times, certainly far more prominent heights than they are to-day, remained above water as islands; and another island may well have existed as a relic of the high ground on the east of the Welsh Lake with a ridge connecting it to the western group.

The higher parts of these ridges would have been exposed to atmospheric waste during all Old Red Sandstone time. They would probably have been denuded of their softer parts and would stand out as peaks of hard rcck such as would yield but little debris. The small size of the islands, coupled with their texture, would account for the absence

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Building of the British Isles, page 86.

of land derived material. If, moreover, we assume that these islands drained towards the region of the Irish Sea or St. George's Channel we have a full explanation.

The rapid change in moving from the Northumbrian district to the central valley of Scotland was no doubt due to a chain of long islands lying along the line of the Cheviots and the southern uplands, the tops of the long ridge which had previously formed the southern shore of the great lake.

The forests and lagoons of the Caledonian region were devastated from time to time by the outbursts of neighbouring volcanoes. Great floods of lava were poured out, and now lie as successive sheets intercalated among the other beds, and interspersed with layers of volcanic ash. There are numerous places in Ayrshire, and still more in Fife and on the southern shore of the Firth of Forth, where some of the ancient hills from which eruptions came have been preserved almost uninjured. The ruined cones have been buried under other deposits, and in recent times these newer rocks have been cleared away, leaving us sections which show many of the details of volcanic action in wonderful perfection.

The Carboniferous Limestone is everywhere covered with a great sandstone foundation known as the Millstone Grit, which changes its character as we go northward, much as the limestone does. It probably indicates a general shallowing of the sea and an accompanying upheaval of the neighbouring lands. It is thick around the district of the Midland Island, or Island group, and is especially thick between this district and the Cumbrian Island. This suggests that a large part of its materials may have come from the shores of these spots.

It is overlaid throughout by the productive coal measures, which make up our coal fields, the total thickness of which has been estimated* at 6,500 feet in Somerset, 8,000 feet in South Lancashire and 2,900 feet in Scotland.

The coal measures are, throughout, deposits of the shore lagoon type. They indicate a slow and prolonged

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Geikie Text Book, p. 1048.

subsidence accompanied by irregular movements which here let in the sea with its marine creatures, and there upheaved a district so that it underwent erosion.

It is difficult to picture the exact physical geography of the time. In these days there does not appear to be any part of the earth where similar conditions present themselves. Indeed, although productive coals do occur in rocks of widely different dates, the richest coal fields of Europe, Asia, America and Australasia are all of about the same age. The only conclusion possible is that the terrestrial conditions of the time favoured the accumulation of vegetable matter more fully than ever before or ever since. The conditions seem to have been slow oscillating movements interrupted by long pauses, but on the whole a subsidence. This must have been accompanied by abundant rainfall and sufficient warmth. It has been suggested that the atmosphere was more highly charged with that essential food of plants, carbonic acid gas, than it is at present. This is quite possible, but there is no evidence. It has also been suggested that the earth enjoyed a widespread tropical climate, but this is negatived by the occurrence of undoubted glacial deposits in India, Australia, and South Africa. These are questions of great general interest, but for our present purposes it is enough to picture the country north of the Bristol Channel and the Somerset flats as an extensive swampy forest interrupted by the hill region of Wales and the Midlands; then more swamps till we reach the slopes of the Grampians and the Donegal Mountains, which still formed part of a diminished mountain chain flanking a large North-Western Continent.

It has been said that the Old Red Sandstone passes up quite comformably into the basement sands and shales below the Carboniferous Limestone.

If we now turn to Devonshire we find, in the few places where the passage can be traced, that the topmost Devonian rocks shade off quite gradually into others of Carboniferous age which are known as the Culm Measures. The boundary between the two systems is often obscured, and in many places the division is a line of fault, but in North Devon

it is fairly well defined by the valley along the line followed by the Railway from Taunton to Barnstaple. The earliest beds of the carboniferous period are a series of thin shales, often very dark in colour, and which are overlaid by impersistent beds of Limestone of peculiar character, and these are in turn covered by thin even bedded cherts. These beds, known as the basement beds, have been greatly broken, folded, and in places crumpled so that it is very difficult to be certain of the exact order in which they succeed each other. But taking all the exposures together there is no doubt as to the true sequence.

The question at once arises whether these black and dark grey shales and overlying limestones and cherts are the local representatives of the basement shales and the Mountain Limestone of the Mendips, South Wales and the Midlands. It is answered by the fossils found in the two series. The shaly partings between the limestone beds of Devon, and the shaly beds themselves, contain adundant traces of plants of carboniferous genera. The limestones contain other fossils, some of which are peculiar to the district, while some are identical with species found in the Carboniferous Limestone. Moreover the position of the beds on top of the Devonian strata necessarily implies their identity in time with the rocks immediately above the Old Red Sandstone.

These basement beds may be seen in many places, since both the limestone and the chert have a commercial value, and therefore quarries are opened wherever they occur. The limestone is used for building, for making lime, and in some districts for road metal. The cherts lie in thin beds, generally only an inch or two in thickness, and they are naturally broken up by joint planes, or cracks, which cut up the beds into such small pieces that they need very little additional breaking to fit them for mending roads.

Let us first consider the limestones and their relation to the vast calcareous deposits of the rest of the country.

We lost sight of the Carboniferous Limestone after we had seen it at its maximum thickness in the Mendip Hills. On their southern edge the beds dip down under the modern alluvial flats of Somerset. About twelve miles away towards

the south-west we find an isolated patch of similar rock rising up between the Parret and the Quantocks in Cannington Hill, but it is surrounded on all sides by newer deposits, and we can only identify it and note that it proves that the conditions remained unchanged, or not materially altered, so much further south.

Crossing a belt of country about seventeen miles in width, which consists partly of Devonian rocks and partly of much younger deposits, we reach the neighbourhood of Burlescombe Station, about half a mile to the west of which a number of abrupt, but low, hills rise from the new rocks by which they are surrounded, as a group of limestone patches, where there are very large quarries. The rock is here considerably darker in general tone than the Mountain Limestone. It contains fossils of carboniferous date, but they are few and far between, and principally exist in the thin red shaly layers which separate the beds. The fossils are restricted to a narrow band which does not seem to be opened in all the quarries. A small one, a little south-west of Westleigh, is the most prolific. Here certain beds are crowded with fossils, mostly such as might have lived on the floor of a fairly deep sea or have moved freely in its waters. They are nearly all flattened out, so that they appear only as markings, or very thin films on the surfaces of the shales or limestones. But mixed with the animal remains there are abundant traces of plants of early carboniferous age.

The limestones are frequently banded with cherty layers which are specially frequent in the upper beds, and according to Messrs. C. J. Hinde & Howard Fox* some of the limestone beds are of foraminiferal origin.

Among the fossils there are several species of Goniatites, the creatures which were the precursors of the Ammonites which became so abundant later on, and shells of bivalves known as *Posidonomya Becheri*, and *Posidonomya Lateralis*, both of which are extremely abundant in certain beds. Crinoidal remains are numerous, and on one

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**Quart. Jour. Geol. Soc.*, 1895, p. 620.

occasion a large one was uncovered lying almost complete as if it had been entombed where it had lived.*

Similar beds can be traced through Holcombe Rogus and Ashbrittle. There is then a gap until the great quarries of Bampton are reached.

Here the Posidonomya beds occur again, and some of the Goniatites are found, but fossils are less numerous, the limestone is much darker in colour, and the total thickness of the series is certainly less.

From Bampton it can be traced every here and there along a line lying south of Barnstaple, and as it goes the change in the character of the stone and its diminution in thickness progresses, until we get the coal black rock of Venn.

It will be remembered that the limestones at Westleigh were banded with chert. At Bampton similar cherts are seen, and at both places it is possible to get blocks of solid stone streaked across with several cherty zones, showing that there was no pause between the two deposits, but only a somewhat gradual change in its character.

If we now cross over to the line where the basement beds lie on the southern Devonians, we find similar broken exposures of limestone running round the northern limit of Dartmoor, as at Drewsteignton, Okehampton, and Bridestowe. In all these places it resembles the black rock of Venn, and it is evidently of the same age, as it contains the same fossils.

Now the black limestone owes its colour mainly to the presence of finely divided carbon, and on ignition this can be burnt away and a white or very pale lime is the result. Moreover, according to analyses of the Drewsteignton limestone† it contains actually 62 per cent. of silica with only 30 per cent. of carbonate of lime and nearly 1 per cent. of carbon.

Before considering the interpretation of these facts let us examine the overlying chert beds. They have long been

* Found by the members of the R.A.M. College Field Club.

†Kindly made by Mr. F. Southerden, B.Sc., F.I.C., Lecturer in Chemistry at the R.A.M. College, Exeter.

Thin bedded Black Limestone, Drewsteignton.

Thick bedded Grey Limestone, Westleigh.

known as the Coddon Hill beds, from a conspicuous hill about a mile south of Barnstaple, and forming the southern side of the valley in which the black limestones of Venn were formerly worked. In a quarry, on the north-west of the hill, the beds are admirably shown. There are some of them almost as hard as porcelain, and of various dark or mottled shades of colour, but some are streaked with white, like a porcelainized flint, while some of the intervening beds are a powdery pale grey shale which can be crumbled between the fingers.

Precisely similar beds form a line of bold hills stretching eastwards to near Ashbrittle. Here they are lost, and are apparently represented by the chert bands so intimately associated with the limestones of Westleigh and Holcombe Rogus.

The same beds crop out above the southern limestones and have been traced from the Cornish coast past Launceston, round the northern edge of Dartmoor, to the neighbourhood of Chudleigh.

When, in 1893, Dr. Teall and Mr. Howard Fox discovered the Radiolarian origin of the chert at Mullion Island, the idea suggested itself to many that the Coddon Hill and other chert beds might possibly have been formed in a similar way, so that when in 1895 an exhaustive paper on these beds was read before the Geological Society by Mr. Fox and Dr. G. J. Hinde, Devonshire geologists were not surprised to learn that it was proved that these basement beds of the Culm repeated the deep sea phenomenon of the earlier date.

We are now in a position to attempt a reconstruction. We may regard the massive limestones of the Midlands as the solidified ooze of a moderately deep sea. It will be remembered that while there was land where the Carboniferous Limestone was subsequently deposited there was open sea over Devon. If now, as we have pointed out was possibly the case, the rather rapid subsidence was general over a wide district, a lowering enough to convert the land into a deep sea would necessarily convert the neighbouring seas into very deep ones.

Let it be granted that this occurred. Then as we pass from the old shore lines we should find the bottom rapidly sinking. At first the foraminiferal mud would be able to accumulate, but the water being deep the calcareous matter in the ooze would bear a smaller proportion to the whole, and the greater the depth the larger the relative amount of silica would become. Throughout the district the total thickness of sediment accumulated in a given time would be less than in the neighbouring shallower sea, and the greater the depth the thinner and more siliceous the deposit. If, then, we consider the Westleigh cherty limestones to have been formed in deeper water than the lower part of the Mountain Limestone we easily explain its differences. If also we suppose that the sea deepened westwards and south-westwards we account for the high percentage of silica at Drewsteignton and the much smaller thickness of the limestone as a whole. But the subsidence was not limited to the brief time between the top of the Old Red Sandstone and the bottom of the Mountain Limestone. It must have continued long after the formation of the latter had begun. In Devon, therefore, the deep sea of the early part of the period would grow deeper and deeper. In the Midlands it is quite possible that accumulation kept pace with subsidence, so that the sea maintained a nearly constant depth. If so, and if Devon shared in the downward movement, the slower accumulation would fail to keep pace with the subsidence, and the sea would steadily deepen. At last the conditions would be such that all the calcareous matter was dissolved before reaching the bottom, and the result would be a Radiolarian ooze such as Messrs Fox & Hinde have traced wherever the Coddon Hill beds can be found and even into the cherty bands of Westleigh and Ashbrittle.

The argument seems sound, and indeed the conclusions may very possibly be true. But there are four difficulties.

In the first place the Devonian rocks in both North and South Devon which immediately underlie these basement beds of the Carboniferous do not indicate deep

water. It seems therefore unlikely that the difference in depth between Devon and the Mendip region would have been great enough. Still less probable does this seem when we think of the coral islands and volcanoes of South Devon.

Next, the series of rocks which lie above the cherts do not indicate deep water at all. We must, therefore, suppose a very rapid subsidence at first, and at the close of the deep water period an equally sudden great upheaval. True, the sudden incoming of the millstone grit above the Mountain Limestone does point to rapid change of the kind we need, but the change from a Radiolarian abyss seems too great to be very likely.

Again, how are we to account for the abundance of organic matter in the black limestones and black shales, so closely related to each other and to the cherts. From the bodies of the Radiolaria and other organisms? This is possible, of course, but hardly likely.

Lastly, we have the occurrence in great abundance of traces of vegetation. At Westleigh plant remains are more abundant than other fossils, and in most of the quarries where basement beds are exposed we find similar fossils, often excellently preserved.

Now plant remains are always regarded as an indication of nearness to some shore, and of a shallow sea. How is it possible to reconcile such a conclusion with the abysmal theory? It seems most unlikely that so many, and in some cases such well preserved plant fragments could ever reach a great enough depth to be interstratified with abysmal deposits.

It will be remembered that the solution of the calcareous matter and consequent formation of a purely siliceous deposit is not, as a matter of fact, directly due to depth, but only indirectly. The water at great depths is more highly charged with carbonic acid, and it is this which effects the solution.

If, then, we can find some other reason for thinking that the water over Devon was more highly charged with the solvent gas we shall have a cause quite adequate to explain the facts observed.

This we have in the organic matter, and particularly the plant remains.

It is well-known that dead vegetation in the process of decomposition forms a number of organic acids such as the bodies known as humic acid and ulmic acid, which soon break up, and in turn give rise to carbonic acid. When water is loaded with rotting leaves or other vegetable matter it becomes a powerful solvent of carbonate of lime, and very much of the dissolving action of rivers, lakes and ponds, and of rain water which has percolated through the soil, is known to be due to the presence of these products of decomposition.

If now we suppose that the subsidence, so even and regular over most of the British Area, did not extend much further south than, let us say, the English Channel, but left dry land not far away, on the south or east or west, we should account satisfactorily for the plants which can hardly have been drifted from the central island across the Carboniferous Limestone sea ; and we also discover a source from which the other abundant organic matter came. We should then regard the Devonshire sea not as one of unusual depth, but as being more or less girdled by low lying land thickly clothed with plants descended from those which spread over the old continent, and drained by sluggish rivers heavily laden with vegetable products which they poured into the land locked sea. If we imagine this sea little disturbed by tidal or other currents, we have all the conditions which we want.

These two views are the complete opposites of each other, and time may show that the abysmal theory is the correct one, but in the meantime the sequel will give yet other reasons for inclining to the idea of a stagnant sea laden with vegetable matter.

The basement beds shade upwards into dark shales and slates interspersed with occasional thin beds of grit. The two groups are so closely related that Mr. Ussher has regarded some of the lower shales as actually having been formed in some spots while the Coddon Hill cherts were growing not far away. They all consist of land derived

material, and on the abysm theory must mark a considerable upheaval, sufficient to bring the shores much nearer to Devon, or to greatly increase the carrying power of the rivers. This series of beds he calls the Exeter type of Culm measures, from the fact that they are admirably displayed in numberless sections on the northern side of the city. Every roadside cutting shows them more or less, and they can be well studied along the road to Cowley Bridge and on towards Stoke Canon. They are singularly devoid of recognizable fossils, but some of the shales show markings which suggest that they were made by shells which have since been removed. Their general colour is grey, but there are purple stains which have probably been caused by subsequent events. Here and there the colour is a pale drab, a tint shown repeatedly where the beds are more gritty.

The grain is always fine, even in the thickest grit beds, so that the land from which the material came was probably some distance, say twenty or thirty miles away. It is hardly likely that it was much further off, as the whole series is interspersed with beds which are full of obscure evidences of vegetation. In the neighbourhood of Exeter, although there can be no doubt that the remains are those of land plants rather than seaweeds, they suggest the idea that the leaves and stems were rotten when entombed.

Generally speaking, the basement beds of black shales, limestones and cherts are over-laid by a series of the Exeter type. But the district around Chudleigh offers an exception which is very significant.

So long ago as 1840 Sedgwick and Murchison pointed out, in their Report on the Physical Structure of Devon, that in Ugbrooke Park there occurred coarse sands and conglomerates. De la Beche pointed out that these beds contained pebbles apparently derived from "Carbonaceous" deposits, by which he meant the Culm basement beds. Mr. Ussher has pointed out that in fact they do lie on top of the basement beds, replacing the normal succession strata of the Exeter type.

They contain numerous fossil plants in a state of good preservation, such as to indicate very plainly that they were

formed in shallow water certainly not many miles away from shore.

There are similar beds on the west of Dartmoor, but their position is not so easy to determine in consequence of the greater complexity of the present structure of the district.

Now there is no doubt that the series of deposits which succeed the basement beds are the southern marine representatives of the shore lagoon swamp beds or coal measures of Glamorgan and the Midlands. These we have already attributed to a change which resulted in a considerable shallowing of the Carboniferous Limestone sea. Slow and intermittent subsidence followed, but it is evident that the period of maximum submergence had passed and the time had been reached when earth pressure had again set in. It will be remembered that the upheaval which closed the Protozoic cycle and created the Caledonian-Scandinavian chain was prefaced by local upheavals of the floor of the Silurian Sea. Here at the close of Deutozoic time we find the same sequence of events, and it is evident that the Ugbrooke Park beds mean one of two things—either that the sea bottom was suddenly upheaved from a depth perhaps of 2,500 to 3,000 fathoms until part of its floor was subjected to surface erosion, or that the southern low islands, whose existence we have supposed, were lifted higher, so that the rivers no longer flowed into the Devonian Sea loaded with the refuse of vegetable swamps, but that they rushed swiftly down, carrying sand and pebbles to the shore, and spreading ordinary mud, more or less mixed with plant fragments, wherever the Exeter rocks are now found.

Lying above the rocks of the Exeter type we find a series in which the fine shales are still numerous, but, instead of being separated by thin fine grained grits at rather wide intervals, the grit bands are much thicker and coarser, many of them being actual sand and resembling strongly the sandstones of Ugbrooke Park. These Mr. Ussher describes as Culm measures of the Morchard type. They are well displayed in numerous quarries almost anywhere on the northern side of the long tongue of newer red rocks which runs past Credition.

These in turn are overlaid in the eastern part of the Culm area by a series of massive grits and sandstones among which the shales are only represented by thin layers which serve to separate the coarser beds. These are well shown around Eggesford, and are therefore named by Mr. Ussher the Eggesford Grits.

The Devon Culm Measures, then, from the top of the basement beds upwards through the whole series are indicative of shore lines not far away and approaching nearer and nearer. From bottom to top they contain numerous remains of plants which have been identified as belonging to the same period as those which make up our English coal. This has been particularly emphasised in recent years by the labours of Mr. Inkerman Rogers, who has found in the Culm beds near Bideford, not far removed from the so called anthracite bands, numerous well preserved plants and a mollusc known as *Carbonicola* which has long been known as an inhabitant of the coal lagoons. These fossils have been described by Mr. Arber, and it seems that they form a strong argument against the abysmal theory of the underlying basement beds.

The "Anthracite" is an impure coal which is found in seams interstratified with the Culm, and there is no doubt it has been formed from vegetable mud drifted from the coal swamps of Glamorganshire.

So far we have said nothing of volcanic action in Devon during the deposition of the Culm series, nor have we reached in time beyond the first indications of the great transformation of the map which closed the Deutozoic cycle. The two sets of phenomena are closely related to each other, and must form the subjects of another chapter.

CHAPTER V.

The Great Upheaval.

We have, so far, seen the Devonshire area only as one over which more and more materials had been accumulating; a region in which bed after bed of rock had been laid down, some as sheets of gravel and sand and mud, the waste of neighbouring lands—some as floods of lava or showers of volcanic ash, and some as the debris of vanished forms of life. The same general sequence of events had been going on over a broad belt of the European area stretching from our own south-western counties far to the eastward. It had gone on without intermission during a vast lapse of time which had witnessed stupendous changes. The Cambrian shores had been converted into the Ordovician Ocean, this into the lakes and mountains of Old Red Sandstone days, and these again into the seas and forest swamps of the Carboniferous period.

A deep broad band of soft and uncrushed material had thus been built up in the earth's crust, forming a district which was certain, sooner or later, to feel the effects of terrestrial shrinkage. Moreover, this weak region was bounded on its northern side by one in which the upheaval of Protozoic age had already compressed and hardened the rocks, and which was therefore specially rigid. Indeed, the conditions which we have seen resulted in the crushing up of the earlier sea floor against the relics of a north-western land area were reproduced again with but minor differences. The old Caledonian-Scandinavian chain ran approximately from N.W. to S.W., since the earth pressures acted from the sea towards the ancient coast. Here, at the end of Deutozoic time, the pressures acted from the south, and the accumulated sediments were folded against a northern land, rising into a series of ranges which lay in a general east and west direction. They stretched from our most western coasts through the northern part of France, the forest of the Ardennes, and the coal fields of Belgium away into the

centre of Europe and beyond. This was the second great mountain chain of the European area, and in its prime it must have been fully as important as its predecessor. Its parallel ranges extended from the Mendips almost to the Loire; and the hills and mountains of Killarney, Devon and Cornwall, Brittany, the Ardennes and the Hartz have been carved by the wear and tear of time out of its framework, just as the Grampians and the Southern Uplands of the Scottish border are relics of the earlier chain. Two names have been given to it, the Hercynian chain, from the region of the old Hercynian forest through which it runs, and the Armorican chain, from the old name for Brittany.

The foldings due to the southern pressures were complicated in a peculiar way over the British area. If we refer to the map showing Old Red Sandstone geography we see the Caledonian system of ranges would join the newer set somewhere a little south of Killarney. The bulk of the British area was thus pinched up in the angle between the two converging lines of uplift, so that a smaller system of folds and fractures was produced in which the ridges and troughs ran approximately north and south. One very prominent range thus formed still stands as the principal feature in the scenery of Northern England—the Pennine range—hence this minor set is known as the Pennine system.

The effect of the double system of foldings was to disturb the structure of the country in an extraordinary way, which is probably best understood by reference to the behaviour of waves. Anyone who has watched a rough sea with long rollers sweeping in obliquely against a sea wall, such as the walls which guard the Great Western Railway at Teignmouth and Dawlish, is familiar with the behaviour of two sets of waves crossing one another. As the incoming rollers sweep landward they are crossed by a smaller set reflected from the wall and moving seaward. Where the crest of one wave coincides with the crest of the other the water is thrown up into a dome or point, and where the crest of one happens to fall on the trough of the other the surface may stand almost at its normal level.

The folds of the earth's crust are similar. The hard, firmly welded base of the Caledonian-Scandinavian chain may be likened to the sea wall, the grand folds of the Hercynian system to the incoming rollers, and the Pennine folds and fractures to the reflected waves. The two alternately reinforce and neutralize each other and sometimes deflect each other from their normal line.

Just as is the case with reflected waves, the Pennine disturbances are greatest where they abut upon the wall, and diminish in intensity as they recede. They join the Caledonian system in the Lake district, and as we trace them southward they become less and less marked until in the Devonshire area they have only a minor importance.

The main ranges of the Hercynian chain lay where the English Channel now exists, or even further south, and as we go northwards the folds become smaller and less abrupt. In the North of England they take the form of broad and rather gentle curves, which tend to throw our coal fields into a series of shallow troughs running east and west. But the troughs narrow and the folds get sharper as we move southwards.

When we reach the Mendip Hills we see the first conspicuous existing feature due to Hercynian folds. They form part of a ridge which rises up at its eastern end on the borders of Wiltshire, and runs through Somerset and across the Bristol Channel, and is continued as the southern lip of the Glamorganshire coal field to the coast of Pembroke. It is a sharp anticline in which the Carboniferous limestone is thrown into a prominent arch which, in the Mendips themselves, dips northwards under the coal basins of Bristol and Radstock, and southwards plunges under the recent alluvium of the Somerset flats. It is probably somewhere under this district that the productive coal measures change into the unproductive Culm of Devon, but the presence or absence of coal on the southern side of the ridge awaits decision until some adventurous capitalist will put down a trial boring.

On the southern side of the Severn sea and the Bridgwater flats, the Devonian rocks rise up as the wreck of a much larger range. Much larger it must have been, because the

signs of compression are very much more intense. We have no need to quote details again. We have already described them when considering the North Devon rocks. How much larger the ridge may have been it is difficult to say. If the succession of the beds is as Dr. Hicks supposed, that is to say, if the Foreland grits, the Hangman grits, and the sands and grits near Barnstaple are only different parts of the same series of beds and are of approximately the same age, then we have only to imagine these beds continuous over the intervening high ground, with the Carboniferous (Culm) rocks on top of all, to get some notion of the magnitude of this Exmoor ridge. On a very rough estimate for the thickening due to folding it may well have reached three or four thousand feet above the present summits of Dunkery Beacon and the Brendon Hills. In such a case its northern slopes probably lay only a few miles nearer to the coast of Wales than the present cliffs of Lynton.

On the other hand, if the more orthodox theory of the North Devon structure is the truth, the Lynton and Foreland beds are the actual core of the ridge, and we must imagine at least twice as much material piled above the modern hills, bringing the summit to eight or nine thousand feet, and throwing the northern face of the ridge so many miles further north that it will leave very little room for the trough which must have lain between this range and the Mendip ridge beyond.

We shall find later on an excellent reason for believing that these northern slopes were, in fact, not very far from the line of the present hills, and although the argument is not one which could be pressed very far in itself, it goes at least a little way to strengthen the reasoning set out by Dr. Hicks.

In either case it is evident that the Exmoor range, continued eastward by the Quantocks, must in Post Carboniferous time have been a far more important feature in the local scenery than the great hills so familiar to us to-day

As we step from the Devonian rocks on to the basement beds of the Culm we pass from arch to trough. A

great shallow syncline extends southwards until we draw near to the margin of Dartmoor, where the rocks rise up again as the abutment of another arch. Throughout this broad syncline the Culm beds are so crumpled and distorted that it is impossible to make any accurate estimate of the compression that they have undergone. It is certain that if they could be laid out flat and the broken blocks fitted into their proper places they would cover a country at least twice as wide as that which they now occupy. Indeed since block has been pushed over block it is quite possible that they might require a district four or five times as wide. But the minimum is large enough to show the enormous nature of the forces which have been at work. At the present time the beds occupy a district from twenty to thirty miles in width, and that is only at most a bare half of what they once covered. Apply the same scale to all Devon—and there is good reason to believe the crushing and compression was far greater in South Devon—and we find that the rocks of the Foreland and the Start are *at least* sixty or seventy miles nearer to each other now than they were before the mountain building throes began.

The effects of compression are not always the same. Sometimes we find the rocks, even the hardest of them, bent into most complicated folds, through which each particular bed can be traced for a long distance. This is the case when the beds are of uniform texture, and when the folding has been effected under the weight of a heavy superincumbent load.

The Culm beds, on the contrary, are so much broken that it is quite impossible to follow the fortunes of any stratum. The hard beds have been broken to pieces at the bends, and the fragments have been forced irregularly into the intervening softer shales. This is especially obvious in the Exeter type of Culm, but it is to be traced also here and there among the younger beds of the Morchard and Eggesford types. The most remarkable illustration in point is shown in the contorted exposures of the basement limestones and cherts. These hard, resistant, rocks have been broken into great pieces which have been bent and buckled

and pushed into the softer beds, so that they stand up in a most irregular manner along the margins of the trough, instead of forming a continuous lip on either side. Thus it comes about that the Burlescombe limestones cannot be traced up to those of Bampton, and these again are disconnected from those further west. They repeat on a large scale the structures shown in miniature wherever a good exposure of Exeter type Culm can be seen. They are a necessary consequence of very great lateral compression acting on a mixture of hard and soft strata which are not at the same time exposed to great vertical pressure.* The Culm beds had only their own weight acting downwards upon them, and the highly broken structure of the basement beds is an indication that the total thickness of the middle and upper Culm was never very great.

This structural indication of vertical pressure has many applications, and we may remark that of all the North Devon beds the Ilfracombe and Morte rocks indicate the heaviest pressure, and should, therefore, be older than those which appear to have been compressed under a lighter load.

It is illustrated again in part of South Devon. Here the confusion of the strata is extreme. The irregular mixture of soft shales and sands and beds of ash, with hard lavas, crystalline volcanic plugs, and massive limestones, has yielded to the lateral compression in the characteristic way. In the district round Torquay it seems certain that the vertical pressure was small, a piece of evidence which fits in well with that of the Ugbrooke Park beds as indicating an incomplete local deposit of culm. Over the whole district it is quite impossible to unravel the confusion and say where any troughs and ridges were. All we do know for certain is that, like all other Hercynian folds, they ran approximately east and west. Indications of vertical pressure increase southwards until we reach the metamorphosed rocks of the Start and Bolt Head. These must probably have lain not far from the core of a range much larger and loftier than the heights of

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* Lord Avebury, *Quart. Jour. Geol. Soc.*, 1905, p. 345.

Exmoor. Just as North Devon, on any hypothesis, is the stump of an arch, or anticline, and the Culm of Mid-Devon is a trough, or syncline, so South Devon is the northern half of a great and complicated anticline, whose southern abutment must have lain far out in the English Channel.

We have no means of estimating the probable height of this ridge from the rocks we see, except by comparing the structures with those of more modern mountains. In Europe the Belgian geologists have estimated that their local representatives of the chain probably rivalled Mont Blanc in stature, and the Devonshire structures compare with those of some of the lower Alpine ranges, so that a height of ten thousand feet or so above the basin of Mid-Devon is by no means an unlikely altitude for our southern range. There can, at any rate, be little risk of error if we picture the Channel as land traversed by parallel ranges of Alpine size, one of which crossed the extremities of South Devon and Cornwall.

The main features of Devonian folding we see are determined by Hercynian folds. But they are not wholly so. The Pennine system, though comparatively insignificant, has left its mark. In the North of England it consists of a series of fractures which cut up the country into terraced steps rising abruptly on the west and sloping gently towards the east. Crossing, as it does, the gentle Hercynian folds, it divides the coal fields into two rows of basins which, in the north, are generally longer from north to south than in the transverse direction.

As we pass southwards the Pennine disturbances diminish and the Hercynian increase, so that the coal fields tend to lie in basins elongated from east to west. Pennine disturbances are not very obvious in Devon, but there is certainly a north and south ridge of Devonian rocks rising up under the newer covering of the Haldon hills, and the basement beds of the Culm are brought up in the Perridge tunnel of the Exeter railway. The Devonian rocks form the base of the slopes on the east of the valley of the Teign to some distance north of Chudleigh. Indications of a northward continuation of this ridge are afforded by

Ideal restoration of Post-Carboniferous Geography.

the Culm masses of Stoke Hill and Ash Clyst forest, and by the trend of the limestones of Westleigh.

The Culm shales and cherts also rise up on both flanks of Dartmoor, and a similar arrangement is shown by the Devonian rocks on the eastern and western sides of the granite bosses across the Cornish border. It has been explained by supposing that the granite existed before the Devonian rocks, or, at least, before the Culm measures were laid down; but the granite shows no sign of having been subjected to the forces which folded the Culm, and the surrounding rocks show no indication of change of composition or texture such as we should expect on approaching a great mass of solid rock. It seems far more probable, and we shall see later on, almost certain, that the granite rose to its present positions in a fluid state after the earth pressures had done their work, and that those positions were determined by the folds, and did not in any way determine them.

If we bear in mind what was said earlier about two sets of waves crossing each other, and remember that there must have been many points where the Pennine undulations reinforced the Hercynian, it is easy to understand that Devonian and Culm may have been thrown up into a number of dome-like structures above the subterranean lava reservoirs which had fed the volcanoes which were so active throughout both periods. This we believe to have been the case, and that the molten material rose up into these domes and ultimately became the granite bosses. The exact age of the granite and its connection with the volcanic rocks have been the subjects of much discussion, and many theories have been advanced. Their consideration will come more profitably later on. It is enough to point out that the structures shown by the surrounding rocks can be easily explained as due to the crossing of the two sets of folds which we know existed all over the south and west of England. We must, then, in our attempt to reconstruct the geography of the time, picture the heights of Dartmoor and Bodmin moor as replaced by elevated districts composed of folded Devonian and Carboniferous rocks, piled up

above the present contours to heights of which we can form no confident guess.

Nor is this all. In this description of the Great Upheaval we have said nothing of the manifestations of volcanic activity which seem to be the invariable accompaniments of all great earth movements, and which were so intense in Devon that they have left as large a mark on the present scenery of the county as anything we have described. It will be shown in the next chapter that the Dartmoor dome must have been more or less covered with volcanic products, either arranged as Mr. Worth has suggested* in a great composite volcano, or in a number of smaller cones and craters high above the present contours of the moor.

* *Quart. Jour. Geol. Soc.*, Vol. xlvi., p. 69.

One of the Teign Valley Volcanic Rocks near Bridford.

CHAPTER VI.

Volcanic Rocks.

The story of the volcanoes of Devon is one over which there has been much dispute, and about which there are differences of expert opinion, even greater than those to which repeated reference has been made about the North Devon succession. In order to weigh the evidence accessible, it will be necessary to briefly consider some of the general principles which seem to govern volcanic action.

All volcanic rocks are the result of the cooling of material which has been brought up from a depth within the crust in a fluid state. This fluid, spoken of as the *magma*, appears to collect in vast underground reservoirs, especially on the flanks of a rising mountain chain, and finds its way to the surface in obedience to some impulse which Dana has called the ascensive force.

When part of the magma appears on the surface, it is always found to contain more or less water, which is given off as steam; but whether this water is a necessary part of every magma, or whether it is derived from the passage of the fluid rock through wet surface strata, is a point which is quite unsettled.

If now, a part of some magma cools and solidifies slowly, as it will do at a depth within the crust, its different elements group themselves into definite mineral compounds which crystallize one after the other until the whole is a closely packed mass of crystals. As we should expect, the minerals which crystallize first form well developed crystals, while those which come later have to fill up the irregular interstices, until the last to solidify may seldom have an opportunity of assuming its proper external form.

If another part of the same magma solidifies in a smaller mass, such as an intrusive vein or thin sill, much nearer to the surface, cooling will be more rapid. Before the earlier crystals have had time to grow large, others will form, and these in turn will be surrounded by yet

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another set. The whole mass will thus be crystalline, but the texture will be finer. It is possible that some minerals may have developed and grown to some size before the mass was forced to its final position, and this will produce a rock consisting of large crystals of the minerals which form early, surrounded by a matrix of finer crystals.

Next, suppose the fluid material erupted actually on to the surface. The contained water will flash into steam and form bubbles which will tend to rise up to the surface. If the quantity of water is large the rock may be reduced to the state of an open sponge, or even a kind of froth. There will be all grades, from a rock containing but few bubbles to the familiar pumice, the texture being dependent upon the fluidity of the molten rock, and on the proportion of water.

Where the lava is poured out in a semi-fluid state in a small quantity, it will cool rapidly, so rapidly in fact, that much of its material will set in the form of a dark glass. If, on the other hand it is emitted at a very high temperature in a limpid form, and forms deep floods or streams, the steam bubbles will be mainly restricted to its surface, and the interior and deeper parts may take so long to cool that well defined crystals will be formed, which may leave little or no glass to be detected. Such a lava will be composed of small crystals, and will not always be easy to distinguish from a vein or sill which has cooled quickly.

Lavas, like sills and veins, very often contain some of the early forming minerals in large well formed crystals, bedded in a matrix, which is either made of small crystals, or of glass, or of a mixture of the two.

The first great distinction, then, to be noticed is the difference of texture, which is determined by the conditions under which solidification took place.

Rock magmas differ also in their chemical composition. They are usually represented as consisting of silica and a number of metallic oxides. Silica plays, in nearly all rock forming minerals, the part which is played by the acid in an ordinary chemical, while the metallic oxides are called the bases.

A given quantity of silica can enter into combination with a given quantity of bases to form a particular mineral.

If there is an excess of either acid or base, it will be left to crystallize by itself, unless the elements can so alter their grouping as to use up the excess by the formation of different minerals.

Now a volcanic rock usually contains a large number of bases, and the possible groupings which may be produced is often manifold. The same magma by cooling under certain conditions of temperature and pressure may arrange its parts in one set of crystalline minerals, while under other conditions the chemical grouping may be different. One thing, however, will be unchanged, and that will be the chemical composition of the whole.

Broadly speaking, volcanic rocks are classified in three groups. The first, which contain silica in excess of that taken up by the bases, are called acid rocks. They contain from 65 to 80 per cent. of silica, and granite is their deep seated representative.

Next come the intermediate group, in which the proportion of silica is less. A crystalline mass with granite-like texture but possessing a proportion of only 60 to 65 per cent of silica would be called syenite, while one in which the silica formed only 55 to 60 per cent would be known as diorite.

Reduce the silica below 55 per cent, and we come to the basic rocks, the deep seated examples of which are known as gabbro.

The relations of these crystalline rocks to the lavas, which could be formed from the same magma, will be most easily followed by giving them in a table.

Crystalline or Plutonic Rock.	Lavas.
Granite (Elvans, in veins)	Rhyolite. Obsidian (glassy). Pitchstone (glassy). Quartz-felsite. Quartz-trachyte.
Syenite	Trachyte.
Diorite	Andesite.
Gabbro	Dolerite (matrix coarsely crystalline). Basalt (matrix finely crystalline).

Such are the main divisions used by petrologists. There are, of course, very many varieties in each division indicating the presence of certain minerals. Thus, an andesite may contain mica; if so, it will be spoken of as a mica andesite, or it may contain other minerals instead, in which case it is necessary to name them before the rock can be said to be fully described.

In order to follow the stages in the volcanic action in Devon, it is not really essential that we should go much further into the question of composition except in one important point. Crystalline, or Plutonic rocks, and lavas, are just as liable to alteration after formation as sedimentary rocks, and the precise changes impressed will, of course, depend upon the circumstances which produce them. If, then, one part of a flow, say the material which solidified in the pipe of a volcano, has been exposed to heat and pressure underground, while the lava which flowed from it has been acted on by exposure to the weather, and subsequent burial under newer material, the inevitable result will be that their chemical composition will grow more and more divergent as time goes on, and, owing to the difference in the conditions under which they originally solidified, their constituent minerals may have differed from the start. It may thus come about that we may find the two lying near one another, and yet be unable to say with any certainty that they really represent two parts of a formerly continuous rock.

If we examine the lavas which have flowed from the vents of a volcanic district it is the general rule to find that the earlier extrusions belong to the intermediate group and consist of trachytes and andesites, while the later products include acid rocks such as rhyolite and the basic lavas known as basalt and dolerite.

There are, however, many apparent exceptions to this typical cycle. Instances are known in which it has been repeated with no important break between. In other cases intermediate lavas have made a brief reappearance in a later phase of the cycle, or the basic rocks have been erupted in one part of the area while acid lavas were making their appearance not far away.

It has already been pointed out that the magma which supplies a volcanic district appears to collect in vast underground reservoirs which have a definite size more or less proportioned to the symptoms of activity above them. Years ago it was the common belief that all volcanoes were in some way fed from a molten interior which was supposed to make up the bulk of the earth, or to form at least a continuous stratum on which the solid crust floated like ice on water. This view, however, has been generally abandoned for many reasons which space will not allow us to describe in these pages, in favour of the idea of subterranean lakes whose formation is closely connected with the great earth movements which result in mountain chains.

Changes in the products of activity must mean changes in the magma which feeds them. There is no escape from this conclusion unless we may make the improbable supposition that the changes are produced while the molten material is finding its way to the surface, an explanation of which there is no hint, and which implies a far longer journey than appears generally possible.

The ordinary sequence of changes implies that the usual composition of the magma is intermediate, but that in time the diverse constituents separate into an upper acid portion and a lower or basic part. The solid superincumbent crust will almost certainly present an irregular roof to the lava filled reservoir, and wherever this roof rises highest, there the lighter acid material will collect. Suppose, then, a fissure offers an opening from above into one of these domes, the lava which will be erupted will be acid. If, on the other hand, a fissure formed on the margin of the district reaches down to the side or lower part of the reservoir some of the basic material will escape.

Imagine a time when this separation has not gone very far, and when it is only the topmost domes of the reservoir which are filled by acid rock. It is clearly possible that an eruption may result in an outpouring of acid pumice, or rhyolite, followed by trachyte of intermediate composition, and that in turn by basic basalt, as deeper and deeper parts of the magma are drawn upon. Still more, a

series of violent eruptions may stir up the whole contents of the reservoir and the cycle will be repeated.

At last the piles of erupted material will become so extensive that unless aided by fresh earth movements, the tendency of the melted rock to force its way to the surface will be counterbalanced. The separation of the acid and basic components will then go on steadily until cooling and and final solidification set in, and spread gradually downwards through the whole mass.

If, after crystallization has spread downwards for some little way, the region is disturbed by fresh movements, the solid top of the magma may be cracked in numerous places, and some of the underlying still fluid material injected into the fissures, or even on to the surface.

The differentiation of the contents of the reservoir appears to be brought about in two ways, and it is a matter for discussion as to how far each cause may be the chief.

We have already said that the minerals cystallize in a definite order. We can now go further, and without going into minute particulars, say that the more basic minerals are those which crystallize out first. These are also the heaviest, and some of them are separated while the lava is quite limpid. If this is so they must obviously sink down.

Now it must be remembered that cooling of the contents of a lava reservoir must begin at the top and spread downwards, very little of the process beginning at the sides and spreading laterally. It follows that at a particular level we shall have the temperature about the same, with only slight diminution as we reach the sides.

Very little is known about the exact influences exerted by temperature and pressure upon the crystallization of rocks, but it is almost certain that the separation of a given mineral is strictly analagous to the crystallization of an ordinary chemical from solution. There are two ways in which this may take place. The crystals may be formed on the walls of the vessel, particles of the substance apparently travelling from the interior of the solution to the sides, or to any foreign bodies or already solidified crystals.

This tendency for marginal crystallization is little shown in cooled igneous masses, though Mr Harker and others have pointed to cases in which something of the sort may possibly have happened. The second method of separation is by the formation of crystals throughout the whole mass as soon as its temperature reaches a certain critical value, which depends on the substances concerned and the strength of the solution. It is well illustrated by an extremely pretty experiment. Take a little nitrate of lead, or acetate of lead, dissolve in water, so as to form a solution of moderate strength, and add a few drops of solution of iodide of potassium, when a bright yellow precipitate is formed. Then boil the liquid, and if necessary add a little water and boil again, until the yellow powder is entirely dissolved. Now allow the almost colourless liquid to cool. When the right temperature is reached glittering golden spangles suddenly make their appearance throughout the mass and settle rapidly downwards.

Such, then, is one way in which differences of composition may be brought about. It has been objected that it would be impossible to have cool molten rock floating on a hotter substratum, as the hotter rock must be the lighter. So it would be if the composition were the same, but it would be quite possible to have comparatively cool melted granite floating on hotter molten basalt, just as cool oil might float on hot water. So we may safely dismiss the objection.

There is a second way in which change may be effected, and one which certainly seems to be very important. Suppose the contents of the reservoir to be at a temperature well above their melting point—they will melt off and dissolve some of the rocks which bound it, that is to say, those within which the space has been formed. Next, if we consider the crust above the reservoir, its surface temperature will be that of the locality, its lower surface that of the lava, the rate of fall as we ascend from the melting and dissolving base being determined by the conducting power of the rocks. Suppose, now, the reservoir roof is only just at its melting or dissolving temperature but that

the igneous material at a short depth lower is still hotter, eruptions on to the surface will check the escape of heat by thickening the crust, and will draw off some of the colder upper parts of the magma. Either cause will increase the temperature of the melted material in contact with the roof, and the result must be that the magma will work upwards through the crust, gradually eating away the over-lying rocks and incorporating their materials with its own. If these materials consist largely of sand and grit, as they will if they are sedimentary rocks, the result will be to add to the acidity of the magma in which they are dissolved.

In the previous chapter it was shown that the folding of the Devonian and Culm strata indicated a series of mountain ridges crossing Devon and Cornwall, and that these were intersected by minor disturbances of Pennine character, which threw up some of the Hercynian ridges into detached domes.

We now see that we may consider the abundant volcanic rocks of middle and upper Devonian time as having been supplied from a lava reservoir which underlay most of Devon and all Cornwall, and extended further westward at least to the Scilly Isles. The same reservoir persisted through Carboniferous times, and may even have been connected with the one which supplied the more extensive eruptions which took place at about the same time in Brittany.

Then came the earth pressures. The first upheaval took place over Devon at the close of the Culm basement beds epoch, and this was followed by the great uplift and stupendous folding already described, at the end of Carboniferous time. Then it was, according to the view already sketched, that the molten material rose up into the domes and their connecting arches, and most of the pipes and sills which we find injected into the Culm were forced into their present position. How long afterwards the activity persisted we have no means of knowing, but the time was considerable, for we find lava streams of great size occupying such positions that it is clear the earth's movements must not only have ceased, but denudation must have gone on for ages before they flowed down the slopes and solidified.

The next step is to describe the volcanic components of the Carboniferous rocks of Devon, and see how far they bear out this view.

They are abundantly displayed on both sides of Dartmoor. The crumpled Culm basement beds upon its eastern flank contain numerous interbedded sheets of undoubted lava, and a few beds of interstratified tuff. Both have been greatly altered. In the case of the lavas the steam holes have been filled with mineral deposits, some of the original minerals have been completely changed, so that we find one mineral filling a series of spaces which present the exact outlines characteristic of another; others have been partly changed, and new minerals have been developed from the decomposition of the first set. This alteration makes it hard enough to trace out the full history of the rocks, but it is complicated by another difficulty even more serious.

Devon and Cornwall show no signs of having been exposed to the grinding action attributed to the ice sheet of the great Ice Age. North of the Thames the ancient pre-glacial land surface has all been ground up and pushed away in the form of boulder clay. South of that line the soils we see have been forming since a much earlier age, and the slow rotting of the rocks and their contained minerals has, in the south-western counties, reached depths so great as to render it difficult to get specimens which do not show changes due to surface actions. The same deep soil and moist climate give rise to the rich growth of vegetation, and the three combine to make minute exactness in mapping the underlying rocks often impossible.

However, in spite of these peculiar local difficulties a great deal is known, and the evidence all points in one general direction.

If we take the two sheets of the new Survey Map, numbered 325 and 339, we find that the Culm exposures between Haldon and the granite of Dartmoor are chequered with patches of volcanic rocks. It may almost certainly be taken that those which appear as elongated streaks and ovals are either lavas or tuffs erupted during the deposition

of the Culm, or sills injected during the progress of the earth movements. Some of them, Mr. Ussher has shown, share the disturbances with the culm. But many of the exposures give rounded sections on the map, not much elongated either way, and some at least of these can be shown to be intrusive. An intrusive rock must have taken up its present position after the deposit of the rocks through which it passes, and which are baked and altered where they come in contact with it. These intrusive pipes of rock cut across the bedding of the surrounding culm, so that they are almost certainly later in date than the folding.

South of the Culm area, the northern part of the district mainly occupied by Devonian rocks is similarly riddled by intrusive volcanic materials, and there is a high probability that these also, or at least many of them, belong to Carboniferous times.

Now, the study of these rocks is not easy. They are all classed together as "greenstones," which is a comprehensive term applicable to all sorts of basic rocks and the more basic of the intermediate group. A more precise term is "diabase," which further implies that they have been considerably altered. In order to write their history we want to know what they were when they cooled from fusion.

There is no doubt about the Teign Valley lavas. They were originally dolerite, basalt, or the more basic varieties of andesites, but principally dolerites. The intrusive rocks range, so far as is known, from an intermediate rock resembling syenite to a fairly coarse grained gabbro. There are many quarries in which these rocks have been worked for road metal, and a walk for a few miles along the road which follows the Teign will show numerous good sections. The stone is exceedingly tough, and requires a heavy hammer and vigorous work if good specimens are to be got. Other sections are shown in the railway cuttings, while the pile of rocks known as Bottor, near Hennock, is the largest block of dolerite, and is so coarsely crystalline that it is a question whether it should not be

regarded as a gabbro. Reference to the table in the early part of this chapter will show that the difference between the two rocks is only one of degree, the latter term applying to a rock which has cooled deep down, and the former to the same mass if it has cooled in the throat of a volcano or on the surface.

Although we have said many of these crystalline plugs and bosses are certainly intrusive, there is not one which has yet been shown to have any connection with a lava stream, nor can we, by studying the lavas and tuffs, make any progress towards locating the centres from which they came. Those which were erupted before the folding have been so crushed, broken, and crumpled that we cannot trace them home. Those which are subsequent to the earth movements, and which probably fed eruptive cones above, are only the pipes which led up to a surface which has long since been removed by denudation. The only definite conclusions we can make from these rocks are that the eruption of basic and intermediate materials began before the earth movements, were continued during their progress, and did not cease until after they were completed. We must, however, note one more point. If thin sections of these rocks are examined under the microscope the crystals, many of which are large and well defined, are found to be cracked, broken, and even crushed; an indication of exposure to powerful stresses which will be referred to further on.

If we turn to the western side of the Moor we come to ground which has been thoroughly studied by Mr. Rutley* and more recently by General McMahon.†

Their investigations have led to important results. Mr. Rutley showed that De la Beche was right in supposing that Brentor was actually the remnant of a carboniferous volcano, and he indicated clearly the site of the vent from which its beds of ash and lavas had been ejected. The original memoir should be consulted, as our space is far too limited

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* *Memoir Geol. Survey on Brentor*, 1878.

† *Quart. Jour. Geol. Soc.*, 1894, p. 338.

to give even a respectable abstract. In its prime Brentor must have been a volcano of considerable size, but not a great mountain in itself. Its rocks have taken part in the earth movements, so that the date of its activity was prior to the main upheaval.

All along the western flank of the Moor the sedimentary rocks are mixed with igneous. Most of them are contemporaneous, but some appear to be intrusive.

General McMahon's paper describes a large number of most interesting rocks, among which there are many beds of more or less altered ash and agglomerate, while some seem to have been lavas which had flowed over loose ash, so that the two became intimately mixed. Some of the ash beds have been re-crystallized, as, for instance, those of Cocks Tor, near Tavistock. Sourton Tors and their neighbourhood are formed of hardened ash, inter-bedded with acid felsites and trachytes, while the little hill of Was Tor, close to Lydford Station, contains an altered basalt and a rhyolite. The beds of agglomerate, he also showed, have been made up from the fragments of a great variety of lavas ranging from Acid to Basic, so that acid lavas must have existed in abundance in cones which were subsequently blown to pieces by violent paroxysmal eruptions analogous to that which destroyed Pompeii and Herculaneum, and to the more recent explosive eruptions in the West Indies.

Where were these volcanoes situated? Can we find their craters, or the pipes which supplied their lavas, or is it possible that all traces of the ancient cones have been swept away, the abrading influences of time having planed them down to the very base from which they came, namely, the lava reservoir itself?

These are the questions which lead to the next chapter.

Photo by F. R. Rowley.

Heltor.

CHAPTER VII.

The Dartmoor Granite and Exeter Lavas.

There are two ways in which a given proposition can be proved. The first is by what is called direct evidence, which means the announcement of a fact or facts which cannot be explained on any other hypothesis than the one. The second is by so-called circumstantial evidence, which usually consists of a number of facts, any one of which can be explained also by some other hypothesis, but all of which find their common explanation in the proposition in question. The larger the number of these circumstantial points the more convincing is the proof, until it becomes every bit as conclusive as the most direct evidence we can imagine.

At the end of the last chapter some questions were asked which we shall now attempt to answer, not by any proof of the first order, but by an amount of circumstantial evidence which seems to the writer to be fully conclusive. It is the fashion in mathematics to preface the proof of any proposition by a concise statement of the theorem which will be shown to be correct. We shall follow this method here, and as we go on shall consider the main objections and rival explanations.

We shall attempt, then, to show that the granite mass of Dartmoor is really the solidified upper part of the cooled lava reservoir from which the Carboniferous and Post-Carboniferous volcanoes of Devon were fed. That it was at one time crowned not only by a great mass of Culm strata, but also by extensive volcanic cones from which acid lavas were outpoured, and from which explosive eruptions built up layers of volcanic ash. Simultaneous with these acid extrusions others of a very different character were taking place, outflows of basic and intermediate lavas of peculiar character issuing from other vents, which presumably communicated with deeper-seated portions of the same magma. Finally, that some at least of these lavas were derived

either from the Teign Valley basic pipes or from similar rocks further west, which were dissolved away by the granite as it worked its way upwards or removed by denudation.

The first point in the chain of evidence is the direction and nature of the folds produced during the great upheaval. This is so obviously related to the granite that there can be no doubt of some connection. Mr. Ussher* has explained this by assuming that the granite was actually in position and cool before the upheaval, and that the uprise of the Culm basement beds around it was the result of their having been squeezed up against it. But closely related to the main granite mass are the elvans or granite veins, which are certainly more recent than the great upheaval, as they cut right though the beds, though the majority follow lines parallel with those of the folds. There must, therefore, have been melted granite under the whole region at this period. If, then, the granite had been solid before the upheaval it must have been fused by the compression, or an entirely new eruption of exactly similar material must have invaded the district. General McMahon,† in an interesting paper, has pointed out the extreme improbability of this view, and very pertinently asks how we can suppose the pressures could have remelted so large a mass, when it produced so small an effect upon surrounding rocks. It is far simpler, and more in accordance with all we know from the study of other districts, to suppose, as we have done, that the granite existed in a fused condition below the surface prior to the upheaval, and that its rise into something like its present position was determined by the particular conditions of the folding. That the main mass of the granite was not solid at the time of the folding, unless indeed fused in the process, is sufficiently evident from two things. We remarked that the crystals of the Teign Valley lavas and those of some of the intrusive rocks were greatly crushed and broken. This can only be due

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* *Proc. Somerset Archæological and Nat. Hist. Soc.*, 1892.

† *Quart. Jour. Geol. Soc.*, 1893, p. 385.

to the strains produced during the upheaval. Now, the crystals of the granite show nothing of the kind. They are sometimes a little distorted, but we know of no instance in which they show such symptoms of rough usage as those shown by the Teign Valley dolerites.

These dolerites and those of the Brentor region were erupted before and during the upheaval. They must have risen from a subterranean reservoir, and from their similarity with each other and with many other rocks beyond the Cornish border, it is impossible to resist the conclusion that a reservoir of the same composition underlay the whole district. Such a deduction is evidently incompatible with the separate existence of the granites in a fused condition, and cannot be reconciled with it in a solid state, unless we suppose either great pillars of solid granite penetrating the basic reservoir, or that the acid rock consisted of quite thin cakes of solid stone above the denser molten mass. No instance of either conditions is known. It is more reasonable, then, to suppose that, at the date of the basement beds, the granite had no separate existence, but that it formed only the upper part of a reservoir which had begun to divide itself into an acid and a basic part. The dome in which this lighter portion collected formed the land from the detritus of which the Ugbrooke Park beds were formed.

Now the extrusions on either side must be supposed to have come from the deeper parts of the reservoir. If any were simultaneously taking place above the granite dome, they must have assumed the shape of rhyolites, felsites, or trachytes, such as those of Sourton Tors. Such lavas are not erupted in a very limpid form, and would not flow far from the vents. They would quickly build up steep-sided cones, from which the processes of denudation would rapidly remove material, thereby affording much of the sandy substance which went to make up the middle and upper Culm.

It should be borne in mind that all which applies to Dartmoor applies with nearly equal force to the neighbouring mass of Brown Willy.

We should thus have two districts made up of materials of granitic composition, amply sufficient to account for the undoubted fact that the Culm of Bude is composed of granitic particles, without assuming that the actual granite was laid bare.

The domes of granite may very probably have been the seat of eruptions from the magma before its parts had begun to separate. Indeed, this is what we should expect to find if subsequent denudation had not done its work so thoroughly. If so, the same districts ought to have supplied a certain amount of debris of trachyte or even andesite, both of which are represented in the Sourton Tors Agglomerates. We should then picture the Devonshire area as resembling the Lipari Islands of to-day, where the ruined central volcano is made of intermediate lavas, while the islands of Lipari and Vulcano are built of rhyolites, and Stromboli and Vucanello of basalts.*

The great upheaval would necessarily squeeze up the domes into a series of elongated bubbles, and the crossing of the two sets of flexures would, with equal certainty cause these bubbles to rise much higher in certain spots where the waves of flexure crossed. Meanwhile, eruptions on both sides of the domes would continue to be fed from the deeper seated magma, while those above the lava filled bubbles would be supplied with acid materials. We should thus expect the elevated districts to be crowned by cones. It is possible that each granite mass represents the base of a single cone comparable with the great mountains of other countries. But it has been said that acid extrusions do not generally flow far. They are viscid, and soon seem to block up their vents with solid rock. This is equivalent to tying down the safety valve, and the result is either the outbreak of new vents near by, or violent explosions which blow away much of the old cone. It is more likely, therefore, that each granite mass represents the base of a district which was thickly dotted over with ruined cones of intermediate composition, and smaller craters and hills built up

* *Judd, Volcanoes*, p. 200.

from the later rhyolites, volcanic glasses, and beds of ash.

As long as the vents remained open, the cooled parts in the upper portion of the reservoir would be drawn off from time to time, and the molten mass would remain hot enough to go on dissolving the over-lying solid crust.

The word dissolving is used instead of melting, because it is found that in some cases a lava which is fairly easy to fuse, has eaten its way through materials which have a much higher melting point, just as the very infusible lining of a Bessemer converter, or a blast furnace, is corroded by the molten slag, unless its composition is properly adjusted. Moreover, there are many places around Dartmoor where hand specimens can be found in which the contact between the granite and the Culm is clearly seen. There can be no doubt from an inspection of such specimens that the granite has reached its present position by dissolving the Culm rather than by simply melting it.

If we suppose the dome of molten material to have been originally covered by Devonian rocks as well as Culm, and that these were largely mixed with, or covered by, the earlier intermediate extrusions, this process of solution would bring the granite through each in turn until it attained to a level so near the surface that the rate of cooling exceeded any possible gains of temperature from below.

Solidification of its upper parts would then begin, and would gradually spread downwards.

But earth movements of great magnitude are generally followed by minor disturbances something like those which precede them. It is therefore probable that the cooling of the whole reservoir would not proceed uninterruptedly. The portions earliest solidified would be cracked open; and fluid material from beneath would be injected into the cracks. Hence the elvans, or granite veins, which are found in great numbers penetrating not only the surrounding sedimentary rocks, but even the granite itself, or at least its marginal parts.

Some of these injections of a granitic magma have a peculiar structure. There is a part of one which may be

seen intersecting the granite blocks of Heltor, above Dunsford Bridge. It differs from ordinary granite by containing large lumps of crystalline quartz embedded in a finer grained granite matrix. Careful inspection shows that it is not a case in which the quartz had crystallized first, but one in which the crystals had been somehow mixed up with the ascending granite. There seems no way of explaining it except by supposing that the uprising hotter molten rock had re-melted all the more fusible minerals of some granite which had already solidified, and the quartz being least fusible, had been left to be carried on in suspension.

Exactly similar rock is to be found in other places, and if we suppose it to have reached the surface, it would have cooled as a lava containing large lumps of Quartz in a much finer grained, or even glassy matrix. We shall see presently what evidence we have of such lavas.

Long after the upper parts of the reservoir have solidified, we may still have eruptions fed from its deeper parts, and these will be most likely to occur by the formation of fissures not through the granite, but on its flanks, especially where the surface has been depressed by a synclinal fold. Exactly such a place is the Teign Valley district which lies between the Dartmoor dome and the Pennine ridge, which we have referred to as running under Haldon and away in a north-easterly direction.

The next points to be considered are as follows:—What evidence have we of the presence of such cones as we have suggested over Dartmoor after the upheaval—and what evidence is there of lava flows from the depths of the reservoir on the flanks of the moor. There will then be a final query as to whether there is any fact which is contradictory to our hypothesis.

The first is capable of an abundant answer in the affirmative. It is supplied by the beds of rock which were laid down all over the east of Devon after the upheaval was practically ended, and long after all movements excepting possibly a few insignificant disturbances.

These are the deep red rocks which form the coast line from Paignton to Torquay, and from a little north of

Babbicombe to beyond Exmouth. They cover the country from Haldon to the foot of the Woodbury Common ridge, send a long tongue up the valley of the Creedy, another shorter tongue from Tiverton to Loxbeare; and then, after lapping round the limestone hills at Westleigh, sweep up the valley between the Brendon Hills and the Quantocks to the northern slopes of Exmoor above Williton and Watchet.

The first point to notice is that these rocks lie unconformably on the upturned edges of the older strata. Near Paignton they may be seen lying almost horizontal on the upturned edges of slates of Devonian age, which are almost vertical. In places along the western face of Haldon similar relations are shown. Close to Exeter there are spots where they may be seen resting in a similar way on the Culm. One very good section was uncovered some years ago at the eastern end of the tunnel between Exmouth Junction and Queen Street Station, where the red rocks lay with a gentle slope towards the south on highly inclined Culm shales.

But there is no need to look for sections in whieh the actual junction can be seen. Thanks to the deep lanes and roadside cuttings so universal in the county, we seldom need go far in order to see something of the geological structure; and everywhere where we pass from the red rocks to Culm or Devonian, we step from beds which are little disturbed, and which have evidently been unaffected by the forces we have described, to others which have borne the full strength of the consequent earth movements. Not only have the red rocks been formed later than the upheaval, but the lapse of time between the first of them and the compressing movements was so long that a large amount of denudation had taken place, so large that in some places the Culm has been removed, and the red rocks now rest directly on those of Devonian age.

We have here a blank in Devonshire history, and, unfortunately, we have no means whatever of gauging its length. It is commonly believed that the red rocks in question belong to part of the Permian period, which was the one immediately following the Carboniferous, but real

proof is wanting. They consist of mixtures of boulders, pebbles only slightly rounded by water action, sharp angular fragments of many kinds of rock, sand, and marly sand, all rather deeply stained by red oxide of iron. Geologically they are described as breccias, sandstones and marly sandstones, and they form the base, so far as Devon is concerned, of the great series of sandy rocks which followed the Post Carboniferous disturbances. As these are rather like the Old Red Sandstone, but are much younger, they were originally grouped together under the name New Red Sandstone. In the Midland Counties and in Germany, where rocks of this time are largely developed, they can be clearly separated into a lower series, called Permian, which is taken as the last period in the Palæozoic era and an upper series, known as the Trias, which forms the first period of the secondary era.

In Devon there is no clear line of division, and it is quite uncertain where it should be drawn, so it is usual to beg the question by adhering to the old term, the "New Red."

The base, then, of the New Red series consists of a great thickness of breccias and sands. The former are admirably displayed in the cliffs by Teignmouth and Dawlish, and in numerous quarries, where they have long been worked for building stone. Most of the old churches of Exeter have been built of it, and in more recent times the great wall which protects the station road at Torquay has been built of similar material.

The fragments of which the rock is composed are largest at Teignmouth and its neighbourhood, and there we find them comparatively little intermixed with sand. But as we move northwards the fragments become rather smaller, and sand is more abundant. Close around the Brendon Hills the texture is coarse, and as we recede from Dartmoor, or from the Exmoor Hills, the diminution in the average size of the fragments is very evident. This alone is almost enough to prove that the two high districts were the localities from which the débris was distributed. But it is not the only evidence. Even more conclusive is a careful examination of the fragments. Near the Brendon

Hills and Quantocks these are broken and slightly water-worn local rocks, mixed with fragments of Culm grit. Exactly such as must have been worn away by denudation from the Exmoor and Quantock ridges we have described, and their presence south of Watchet on the northern slope of the range shows that here, at least, that northern slope is not far from its original position.

In South Devon, near Paignton and Torquay, fragments of Devonian and Culm rocks are abundant, especially the former, and as we go northward the Devonian constituents diminish and the Culm increase That the breccias were made by the accumulation of débris of local rocks is thus assured. In every case the sedimentary fragments can be precisely matched by rock which is in situ not far away in the direction of the existing high ground.

The majority of the fragments moreover show little signs of having travelled far. Waterworn boulders and pebbles do occur, but they are only a very small minority and are rarely rounded to such an extent as to mean a lengthy journey on the bed of a stream. Judging from the analogy of modern rocks it seems that the fragments must have accumulated in steep mountain valleys which were now and then the courses of violent torrents, caused by heavy rains or the melting of snows, which occurred only at long intervals. In many parts of the Egyptian Soudan, in the arid regions of the United States, and especially in the dessicated parts of Turkestan exactly similar deposits are now being produced. During the dry season, or dry years, changes of temperature, oxidation, and the impact of wind-driven particles, act on the rocks flanking the mountain valleys, and the débris falls down the slopes and lies in the valley bottom. At length heavy rains descend, such rains as do fall at long intervals in such countries, and each valley is occupied by a raging torrent which in a few hours clears away the accumulation of months or even years. The streams with their burdens of débris debouch upon the gentler slopes or on the plains, their speed becomes less and their burden is dropped, gradually building up great fan-shaped piles of new dèposit. It makes little difference

whether the new beds are deposited in a lake or on land. The waves of a large lake may round off many of the stones before a new influx covers them up, and the finer mud and sand will be spread further than the coarser fragments and will settle down in more evenly grained beds. But the arrangement of the coarse materials will be much the same in both cases. Such fan-like deposits are known as alluvial fans, and are characterised all the world over by the admixture of coarse and fine material and the scanty signs of wear shown by the fragments.

It seems, then, that the breccias and, therefore, presumably the sands and finer marly beds must have come (in Devon) from mountain valleys further west and from the high ground towards Exmoor.

The New Red deposits north of Exeter afford another piece of evidence which is well worth mention. It will be seen, on reference to the Survey Map, that the two hills called Stoke Hill and Ashclyst Forest are folded Culm and that the latter is surrounded on all sides by the red beds which in one or two places may be seen actually resting on the Culm. There is no doubt that the hills existed in something very much like their present form before the red beds were deposited.

If we examine any rocks which underlie the New Red we find these rocks, Culm or Devonian as the case may be, deeply stained by infiltration of red oxide of iron. The phenomenon has long been known locally as the "raddling" of the rocks, and explains the beautiful red veining of some of the ancient coralline limestones. To take Stoke Hill as an example. When we ascend and step off from the red rocks on to the Culm we see raddling in full force. When we get a little way up the steeper slopes the red hue becomes less marked and presently disappears. As, however, we approach the summit it begins again, and on the top is so strong that we begin to look for patches of still existing New Red. Now, these facts might have been brought about by an upheaval of the hill after the deposit of the red rocks, but in such a case the red beds around would show symptoms of disturbance which are entirely

absent. They can only be due to the hill having existed with rather steeper sides before the red beds were formed. If we imagine layer after layer of red beds to have accumulated around it until they ultimately overwhelmed even its highest point, and then after long ages conceive the wearing away of this ruddy mantle, we have a full explanation. Erosion necessarily follows the valleys and is most rapid on the steepest slopes. On the top of a flat-topped hill wear and tear is at a minimum. Hence a capping of red rocks would remain on the top long after it had been wholly removed from the slopes, and after the valleys had been deeply scoured. Stoke Hill was certainly carved into much like its present shape by the very denudation which produced the breccias and sands. The absence of raddling on the slopes simply means that the reddened layer has been removed, and that the hill is not so steep as it was in the days of its youth, at the end of Palæozoic time.

If, now, we note the position of this hill upon the map and imagine breccia material being derived from the direction of Dartmoor, we should expect that the deposits would be coarser on the side of the obstructing hill which faced their source than in its lee. It is actually found that while the south-western slopes are fringed by breccias they are represented by sands upon the north-eastern side.

Similar arguments show beyond question that the long tongue of red land which runs up the valley of the Creedy fills the bottom of a deeper valley which dates back to the time following the great upheaval. Indeed all along the margin of the red rocks we see the old land surface, which was preserved by burial beneath them, and is only now emerging to the light of day, as the covering is removed by the wear and tear of time. The main structure of the county and many even of its minor features are older than the red rocks.

The breccias, however, are not only made of Culm and Devonian sedimentary rocks. They are filled with volcanic débris. So full, indeed, that there are not a few who believe that they are, in fact, the débris of volcanic cones, or even the far spreading base of a volcanic pile. There is

much to be said for this view, and it is in no way incompatible with our present argument.

These volcanic fragments are full of significance. Mr. R. N. Worth* has made a careful investigation of them in two papers, of which the second is the more important. He shows that they are also mainly of local origin, most of them bits of rock we can still see in situ, but others of exactly the acid and intermediate varieties which ought to be there if our view of the Dartmoor problem is correct, and if the volcanic fragments came from the direction of the Moor. So conclusive does the evidence appear to be that it would probably have been long since generally accepted as proof had it not been for two apparent contradictions—the presence of Dartmoor granite, and even bits of elvans, in the breccias, and the peculiar nature of the lava streams interstratified with them in the neighbourhood of Exeter.

The granite, it has been argued, cannot have risen to its present position after the upheaval and folding, because its solidification must have taken place deep down, and it cannot, therefore, have been exposed on the surface so that fragments could be broken off so soon after that upheaval as the date of the breccias. It will at once be seen that this objection is based upon an estimate of time—the time between the Post Carboniferous folding and the deposit of the breccias. Surely the facts may be equally held to show that the time was long. It has been pointed out that an enormous amount of wear and tear had been effected in the interval, and we must remember that this wear and tear would act most rapidly on the steeper slopes.

A few years ago a boring was put down at Lyme Regis† in a vain quest for coal. It went down 1,300 feet without reaching beds which are known to lie far above the breccias. If, then, the highest land lay where we have supposed it to be, and if the accumulation of débris followed the usual law, and began in the neighbouring hollows, it must have taken a very long time indeed for the pile of deposits to reach

* *Quart. Jour. Geol. Soc.*, 1889, p. 398, and op. cit., 1890, p. 69.

† *Quart. Jour. Geol. Soc.*, 1902, p. 279.

so high up the slopes as the places where we now see them resting. They are supposed by many to be of Permian age. This may be correct, and yet they may belong to its closing years. If so, the lapse of time would be ample for the purpose.

Moreover, we have supposed that the top of the lava reservoir began to solidify soon after the earth movements had almost run their course, but that the injection of the elvans, or granite veins, from the still fluid parts beneath, marked some closing throes. These elvans would, some of them, reach the surface, where they would cool, and a trifling lapse of a few centuries would be enough to lay some of them bare.

In other cases the opening of fissures would be almost certain to give rise to violent paroxysmal outbursts during which not only pre-existing cones, penetrated maybe by elvans, would be blown to bits, but portions of the underlying rock, including the coarse grained granite itself, would be torn off and ejected. Granting, then, that the granite was in position, there is no difficulty in accounting for the fragments even without any great lapse of time, and we have no real evidence that the time was not ample for the earlier solidified granite to be uncovered by simple denudation.

It has also been argued that the granite, when it consolidated, must have been deep down. There is no such necessity. It must have cooled slowly, therefore it must have had a considerable thickness of material above it. It has been pointed out that the breccias require for their formation steep and deep valleys, down which occasional torrents must have rushed with great violence. Some of the partly rounded blocks near Teignmouth weigh tons, and even larger blocks are found near Ide in deposits which are later than most of the breccias. In order to get the slopes we need, we must imagine the valleys of the Teign and its tributaries had no existence, being filled in by the local eruptions, and that over Dartmoor the granite rose above its present surface, and on top there lay the crumpled and hardened Culm, crowned by the volcanic cones built

by eruptions from the lava reservoir before solidification. This will give sufficient thickness of overlying material. Moreover, the size of the crystals and rate of cooling will be affected as much by the volume of the cooling body as by the thickness of the covering, so that there is no necessity to assume a thickness which might not have been penetrated by the joint action of subsequent (elvan) explosions and torrential denudation.

The next difficulty is the Exeter lava streams. They are of very peculiar types, which have been described by the Director of the Geological Survey, Dr. Teall, while their geographical position has been given in detail by Mr. Ussher in the Survey report on the Exeter district. They have also been carefully studied by Mr. B. Hobson.* They may be classed under four types. The first and most basic is represented by the dark chocolate-coloured rock well seen at Ide and Dunchideock, and which lies in a huge mass just under the Belvidere on top of Haldon, where it dips sharply towards the east. It is a basalt, but is peculiar in containing numerous grains and crystals of quartz and felspar, which appear as glassy spots in the rock. Under the microscope it is seen that each of them has a clear interior, but its superficial portion is corroded and looks as if it had been heated to its softening point without melting.

The second type is the paler stone, more the colour of cocoa, which is largely quarried in many places, among which we may mention Pocombe and Posbury. The same kind of rock makes the hill of Rougemont, in Exeter, and crops out again at Raddon, near Thorverton, Silverton, Budlake, Poltimore, and Broadclyst. Sometimes it is massive, with its cracks filled in with deposits of subsequent minerals, giving the stone its veined appearance; sometimes it is as full of steam holes as a modern lava. A line of it crosses Killerton Park through Columjohn Wood to Budlake. It was originally a basic rock, but contains the wrong kind of felspar, the kind which is usually associated with acid rocks.

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* *Quart. Jour. Geol. Soc.*, 1892, p. 496.

Lava Quarry at Pocombe.

Pocombe Lava resting on upturned culm.
The grassy ledge shows the top ot the culm.

The third type is represented by the grey mica-spangled rock of Killerton Park. The lava at the Belvidere on Haldon is separated from the upturned edges of the denuded Culm only by an impersistent band of sand. The Pocombe stone may be seen in the roadside cutting to be actually resting on the Culm. At Killerton the grey lavas rest on, and are separated by, breccia and sand. It has, therefore, been supposed that the Killerton rock is newer than that of Pocombe. But it is quite possible that breccias may have existed at Killerton long before they had reached so much nearer to their source as Pocombe or even Exeter. Indeed, this view is strengthened by the fact that a thin layer of Pocombe type lava actually overlies the grey rocks peculiar to Killerton.

The grey rocks are trachytes, but are peculiar in the quantity of mica spangles they contain.

A fourth type is shown in the large quarries at Knowle Hill near Crediton, and at Marshfield, Loxbeare, and possibly Holmead, near Tiverton. These are intermediate between the lavas of Killerton and Pocombe. They are a kind of trachyte, but it is abnormally basic.

For our present purpose it is not necessary to say more about the composition of these rocks, though they open up many avenues of research. The point is that they are all peculiar, and it might be thought that the vents from which they came might have been identified by a similarity of chemical composition. Nothing of the kind has yet been possible. Geikie* gets over the difficulty by supposing that they flowed from vents which are now buried under later New Red deposits, and that the slopes on which some of them rest are the consequence of earth movements subsequent to their eruption.

But they are intimately associated with the breccias. We have shown that these have most certainly come from the Dartmoor direction, and that some at least of the hill slopes were much as we find them to-day. The breccias must have come down hill, and this is equally certain of the lavas.

* *Ancient Volcanoes of Great Britain*, vol. ii, p. 99.

This direction of origin is well indicated by the distribution of some of the beds which lie very little above the lavas.

It has long been known that the deep red rocks of the hills between Ide and Dunchideock are made of a kind of marly material in which are found many large fragments of a decomposed volcanic rock containing clear lumps and crystals of quartz, quartz porphyry it is called. Fortunately the making of the Exeter Railway involved two long and fairly deep cuttings through these deposits. Before the sides of these were smoothed down they presented an extraordinary sight, being stuffed full of blocks, some well rounded, and varying in size up to huge masses weighing many tons, which had to be reduced by blasting. Some were blocks of hard breccia, some may have been derived from the dolerites and diorites of the Teign Valley, some from the waste of the Ide type lavas. But the quartz porphyry blocks were most frequent, and apart from the red colour of the matrix they might well have been derived from the vein of quartz-containing granite previously mentioned, as dividing the coarse-grained granite of Heltor, which is the nearest point of Dartmoor.

Similar, but smaller blocks, are to be traced here and there towards Exeter, and in the brickfields on the north-eastern side of the city the fragments are very numerous. In Hancock's great pit, for example, we have a deep series of marls marked by irregular horizontal bands of green, and quite a large variety of decomposed volcanic boulders, which are sometimes as large as a man's head. Among them the quartz porphyry is easily recognizable, and so are numerous fragments which must have come from distant parts of the stream of lava which forms Northernhay. Most of these boulders have been much altered. The Northernhay, or Pocombe type specimens, vary from bits whose origin cannot be questioned, through a gradation of changes until we get sometimes a chocolate-coloured block spotted with white (the steam holes originally), which has been altered into a smooth-grained stone as soft as prepared chalk. The writer once marked a set of examinations with a bit of this in lieu of a coloured pencil.

Photo by F. J. Collins.

Ide cutting in course of construction, showing Quartz Porphyry Blocks.

Breccia, near Dawlish, showing sharp angular fragments.
The large block is about 9 inches cube.

But the decomposition of the material is less important than the identity of the quartz porphyry blocks, and their diminution in size as we pass away from Dartmoor towards the north-east, which clearly indicates this as the direction in which they travelled. The stream of blocks also follows the same line as the lava, which suggests that they were swept down the same valley as that along which the lava had previously flowed.

The Posbury stone is in places full of steam bubbles, and in part of the quarry these may be seen to lie in strings pointing away from the moor.

The trachytic types may either have come from a similar point, or they may have flowed down the opposite side of the deep Creedy valley from some point near Tiverton or further north, as, for instance, the intrusive dykes at Rose Ash

In any case there is nothing in the least degree unreasonable in supposing that the cones from which these lavas came should have long since disappeared. The lavas themselves have only been preserved by their burial under later deposits, and the parts we see have not long been exposed to view. Unless the cones should have been similarly buried they could not have survived, and all we could hope to find would be the pipes which fed them.

In the Teign Valley we have a number of intrusive pipes. Some approximate to syenite, some to gabbro, but, so far as is yet known, none of them reproduce the peculiar characters of the lavas we are discussing.

It must, however, be borne in mind that the lavas have undergone many chemical changes in consequence of exposure to the weather, burial under other rocks, infiltration of water, and so on. The Teign Valley pipes have been altered also, but by a different series of actions going on deep under ground. Such intrusive pipes as there are must have solidified far below the surface, and the originally formed minerals may have differed considerably from those in the lavas they supplied.

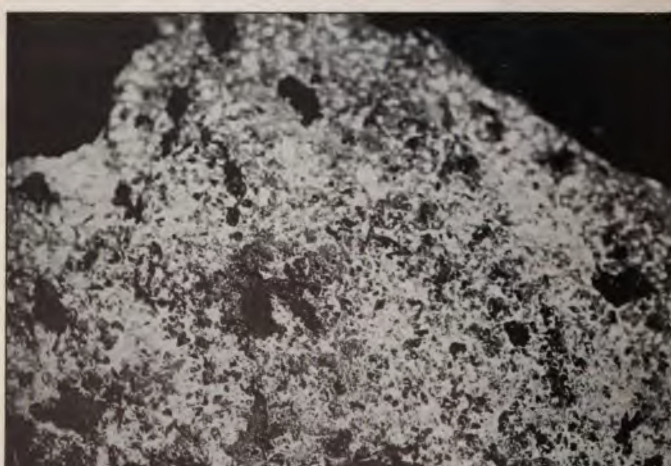
The lavas of Pocombe and Ide must have been erupted in a limpid condition, and on steep slopes such as we have

supposed would have flowed many miles from their source, just as the fluid lavas of Hawaii and of the Icelandic volcanoes have been known to flow for distances of upwards of 50 miles. It is possible, therefore, that the pipes we want may really be some of those in the Teign Valley, or we may find them further away in some of the intrusive rocks of the Newton Abbot district.

Finally, it is even possible that the lavas may have originated on Dartmoor itself. It is not at all unlikely that an eruption of the elvan phase may have been attended by the extrusion of quantities of acid lava, which would not flow far, followed by fluid drawn from deeper zones in the magma which would be less viscous, and therefore flow to greater distances. If the present surface of the granite at the spot where this occurred is below the part then solid, no trace of cone or pipe could now be left.

However this may be, it is clear that the absence of recognizable pipes is no contradiction to the proposition we set out to prove, and the supposed absence of the acid eruptive rocks is a false premise. On the other hand we have a general accumulation of evidence all tending to justify the view that Dartmoor is, in fact, the upper part of the cooled lava reservoir which fed our Devonshire volcanoes, that it rose to its present place in consequence of the Post Carboniferous earth movements, and that it was then and for some time after crowned, or fringed, by active eruptive craters.

Fossil Salt Crystals from the Red Marls.



Spongy Lava from under Southernhay, Exeter.
The large steam holes are filled with black manganese, the small ones with a white mineral.

CHAPTER VIII.

The Salt Lake Period.

The Post Carboniferous breccias are not limited to Devon and Somerset. They are found in several places in the Midland district, from the Lickey Hills near Birmingham, hrough North Staffordshire and North Worcestershire to Shropshire and the borders of the coalfield of Flint. They lso occur on the coast of Cumberland and all along the ale of Eden and on the northern side of the Solway Firth. Generally they consist of fragments of local rocks which can be identified, but the fragments have sometimes been carried uch long distances—up to 30 miles—that Ramsay and others have supposed that they must have been carried by ice. But orrential action such as we have described would be ample or the purpose if we suppose that the hills from which they came were then high enough to have their upper valleys filled by glaciers; and this same supposition also accounts for all indications of ice action, without supposing a glacial period.

These beds, as a whole, rest on the denuded edges of carboniferous and older rocks just as they do in Devonshire, and this is equally true of a different set of deposits which ies on either side of the Pennine ridge. On the west, in Lancashire, we find breccias and sandstones and a thin band of magnesian limestone from 10 to 25 feet in thickness. On the eastern side the breccias and sands and marls are thin, and the magnesian limestone forms a massive deposit reaching through the counties of Nottingham, Yorkshire and Durham to the coast of the North Sea near Sunderland. In Durham it is from 500 to 600 feet thick, and often weathers away in most curious patterns. Sometimes the wasted surface resembles piles of marbles or cannon balls, sometimes it looks like branches of elaborate corals. If, however, one of these objects is broken open, it is seen to to be built up either of concentric layers or to have a radiated structure.

We have already said that the breccias resemble those now forming in arid regions where mountains look down on desert lowlands. We have in the magnesian limestone and its structure another indication of just such a climate. The great salt lake of Utah and other saline sheets of water in the same district are only the shrunken remnants of lakes of far larger size which belonged to a prehistoric time. The shores of these former lakes are fringed by deposits which strongly resemble the magnesian limestone. They have been formed not by the accumulation of calcareous remains of animal life, nor indeed by the settlement of calcareous mud, but by the deposit of material from solution in concentrated salt water. Layer after layer was thus laid down, sometimes around solid fragments of stone, sometimes around some other nucleus, and in time spongy masses were built up whose pores were subsequently filled in by a similar process. Rocks of such a kind are said to be concretionary, and so far as is known, they are only formed in land-locked lakes or inland basins of drainage of the type seen from the Caspian to Lake Balkash, or that which lies immediately west of the Rocky Mountains.

In Germany the great salt deposits of Stassfurt, 1,200 feet thick, lie among similar strata, and show that there, at least, the climate must have been so dry as to completely evaporate a large inland sea, and bring about the crystallization on a vast scale of other chemicals which on exposure to ordinary damp air absorb so much moisture as to dissolve.

The Post Carboniferous upheaval had clearly changed the whole aspect of this part of the globe, by replacing the abundant moisture and luxuriant forest swamps by an arid desert. We see that we must picture England as fringed by the denuded Caledonian mountain system on the north, by lofty points and steep slopes on the west, where the Lake district and Wales now lie, and a great new chain of rugged ridges along the south. Meanwhile the Pennine ridge projected into the plains, and its slopes on both sides descended to the waters of a salt inland lake which existed longest and was largest on the east.

We have no evidence of a similar salt lake in Devon. The sands and marls so closely related to our local breccias do certainly appear to have been deposited in water, and show every sign that the water was shallow and apt to be disturbed by strong currents such as the torrential rushes we have supposed. But these waters may have been fresh, and the Devonshire lake may have drained northwards into the Midland basin, carrying salt and other substances to be deposited by evaporation mainly on the east of the Pennine hills.

A further change followed. The beds we have described are covered by another set, which in the Midlands consist of a lower division consisting of red and mottled sandstones with a central layer of well rolled pebbles, and an upper division of paler sandstones and thick red and mottled marls. This series is often found to lie with a distinct, though slight, unconformity upon the older set. This is one among many reasons which have led geologists to separate the two into systems with different names; the breccias and magnesian limestone series being called Permian and being regarded as the topmost deposits of Palaeozoic time, while the upper set are named the Trias and are regarded as the earliest series of the Secondary Era. A more important reason is afforded by their fossils. Such as they are, those of the lower series of beds resemble the forms contained in carboniferous rocks, while those of the upper set are closely allied to those which follow in the overlying series. This is a piece of evidence of which we can see nothing in Devon, since the whole of the New Red series is remarkably devoid of fossil contents.

The Triassic period is so called from the fact that in Germany there is a middle division composed of fossiliferous limestone, but this is completely absent in England, where there are only two divisions called respectively from their German representatives Bunter and Keuper.

Attempts have been made from time to time to subdivide the Devonshire red rocks in accordance with the system which is applied to their Midland contemporaries. But so far no convincing evidence has been adduced. It is

commonly held that the breccia series, with the Exeter and Tiverton lavas, belongs to Permian time, but there is no evident unconformity to show where this ends. Mr. Ussher would draw the line provisionally above the sandstones which lie immediately above the breccias. Others place it at the base of the great pebble bed which makes the ridge of Woodbury Common, which Mr. Ussher considers to be a probable representative of the missing limestones of Germany. The discussion is interesting to the specialist, but is quite unimportant for the purposes we have in view. The absence of the unconformity so common in the districts further north is in no way remarkable, and may be easily explained by supposing that Devon was too near to the hardened and compressed axis of the Hercynian chain to be affected by the last disturbances of the tract which lay between it and the older chain.

Whatever their precise date, there is no doubt that the red sands shown in the cliffs between Exmouth and Budleigh Salterton were deposited in water. They were irregularly laid down, and signs of the partial erosion of one stratum before the next was formed are to be frequently seen. They are interstratified with beds of red marl, which show irregular bands of a pale green tint. Now and then, when the blocks fallen from the cliffs split open along the original planes of bedding, the surfaces are found to be covered with markings exactly reproducing the sun cracks formed on the surfaces of modern muds when dried, while others show the ripple marks of a sandy beach. Clearly the lake varied in the level of its waters. Deposits mark the inflow of the rainy season, ripple marks and irregular bedding a shallow water time, and sun cracks must mark a rainless period, during which the lake shrank and left its shelving shores to dry.

On reaching Budleigh Salterton we meet with a great bed of well rounded pebbles, which can be traced from the coast all along the Woodbury Common ridge and far inland. It is admirably exposed in many places, where deep pits have been excavated in order to get the pebbles. They are used as a rough building stone to some extent, but their

chief industrial use is for road metal. At Budleigh and along the ridge for a dozen miles the pebbles are chiefly of different kinds of hard quartzite, which is a greatly hardened sandstone. Some of these, which have a lilac tint, when broken open are found to contain numerous fossils, and neither stone nor fossils can be matched in Devon or Cornwall, or indeed anywhere on this side of the Channel. Many of them, however, can be matched from the hard grits of Brittany.

It seems, therefore, that these pebbles must have been brought by a large river or by the action of waves either from Brittany itself, or at least from some ridge of the old Hercynian ranges which have already been shown to have occupied the channel. Many of the pebbles are as large as a man's head, so the current which carried them must have been one of considerable velocity, and must, at least in the rainy season or when the mountain snows were thawing, have been of great volume. It seems almost impossible that they should have actually crossed the Channel, but pebbles of hard rock are carried long distances under the conditions we have mentioned. They afford, therefore, one more link in the chain of evidence which points to mountains like the giants of the Alps lying not very far south of our present coast. They indicate also that the drainage of the chain was from south to north, a point which is further shown by the facts that the stones are largest at Budleigh and dwindle in size as we go northwards, and that the fossil bearing stones become fewer and fewer in the same direction.

Reference has already been made to the division of the Bunter series of the Midlands by a bed of pebbles. This is made of equally well-worn stones, most of which can be matched by rocks which lie to the west and north, the same direction as that from which the materials of the local Permian breccias came. The general contour of the country was therefore similar, but the greater roundness of the Bunter pebbles means, not necessarily a longer journey in miles, but one which involved more knocking about on the way, such as would result from a gentler slope. The breccia

material must have been swept out of the valleys with such force that all except the largest boulders were carried almost in suspension, while the Bunter pebbles must have been trundled along the bed of a fairly rapid river, or one which became so in flood time. The reduction of cliffs and precipices to less abrupt slopes by the progress of denudation will explain the change.

But between the breccias and the pebble beds lie great deposits of sand and marl, a fact which looks as if the two coarse deposits mark two periods of violent floods, separated by a long interval, during which the torrents and streams had been small and unable to carry anything coarser than sand or mud.

It follows from this that the Budleigh pebble bed and those of the Midlands must have been simultaneously formed. They indicate a geographical change of such importance that, unless each can be shown to be due to a local upheaval or some such cause, they can only be attributed to climatic change such as would affect a wide district.

From this time onwards to the close of the Trias, a great lake covered the whole region of the red rocks, and from Budleigh Salterton eastwards, as far as the beds can be traced, they abound in evidences of the saline character of its waters, and the barren aspect of its shores.

From Budleigh Salterton there is a splendid coast walk past Ladrum Bay to Sidmouth. The footpath follows the cliffs most of the way, and although there are not many spots where it is possible to climb down to the beach, many fine sections can be seen from above. In Ladrum Bay itself the sandstones are greatly false bedded, and calcareous concretions of irregular form are common, though this feature is better seen nearer to Sidmouth. At low water of spring tides much of the coast can be visited, but it is a wise precaution to have a boat within call, as there are many small bays in which the water rises to the perpendicular cliffs. Not far beyond High Peak there is a path down to the shore which gives an excellent section of the marls which lie above the sands. On reaching the beach, if we turn westwards and examine the dark red sandstone rocks which form the point,

Base of Budleigh Pebble Bed resting on uneven surface of marl.

Strings and veins of Gypsum in the Red Marls near Watchet.

we find they are in places almost breccias. The surfaces are covered by a network of concretions of calcareous material. Exactly similar things are to be seen at Otterton Point on the eastern side of the mouth of the Otter. Indeed, this section has even greater interest, being the spot where Mr. Johnston Lavis found remains of an amphibious animal known, from the structure of its teeth, as *Labyrinthodon*, and Dr. Carter noticed many traces of bones.

Moving on eastward the 500 feet of cliff under Peak Hill show the marls and sands to perfection. As we go, it is well to break open some of the rounded nodules of red or pale-green stone which lie here and there among the rocks at the foot of the beach. Some of them are hollow, and are found to be concretions lined with calcareous crystals, generally gypsum.

Beyond Sidmouth, a few yards beyond the mouth of the Sid, the sandstones end abruptly against a fault, and the marls descend to the beach itself. It is a heavy pull to walk over the pebbles along the coast to Branscombe, and the section has a sameness which robs it of much of its interest. All the way the cliffs are made of the same red marl, streaked and spotted with pale green. The different beds vary in texture, but, as a whole, the materials are fine, and the bedding indicates fairly tranquil deposit. Strings and layers of nodules of gypsum occur every here and there, while the marls now and then show a curious marking on the original surfaces of deposit. When split open the surface shows a number of square pits, varying in size, but averaging about a quarter, or a third, of an inch across.

If the pits had been round, as they are in some instances from the red marls of the Midlands, they would have been formed by a shower of rain pattering down on the half-dry mud. But square holes!

Now in arid regions, such as we have compared with Britain in Triassic time, we can see the explanation. Cubic crystals of salt separate out from the wet mud as it dries up, and when an influx of fresh water comes they are dissolved and the new mud fills the holes. The markings are

then fossil crystals of salt, and prove completely that the waters were salt.

From Peak Hill eastward the red marls are seen to be capped with beds of pale green grey sandstone and other strata of a buff tint. As we go from Sidmouth to Branscombe these beds come lower and lower until at the landslip of Hooken Cliff they hide the red rocks completely.

These, however, reappear at the bathing cove of Seaton, and form the shore line on to the greater landslip at Rousdon. The pale beds which overlie them belong to a date far later than the red marls and to conditions utterly different, which will be described in their proper place. To confine our attention for the present, then, to the red marls, we can follow them along under the Haven and Bindon Cliffs east of the Axe. It is well to note that this piece of coast has been in a very dangerous condition for several years. The pale beds are porous, the red marls impervious, so a line of springs issues along the junction, and the result is frequent slips and falls of material, which build up sloping screes. The stones which lie upon the beach are chiefly fragments of the pale beds, but among them lie numerous concretions of the same character as may be seen further west. They are often filled with beautiful glittering crystals of gypsum.

The cliffs themselves show frequent little faults, and the division of the deposit into distinct beds is clearly shown. Some whole beds are green in colour, and as we near Culverhole, where the landslip reaches the sea, we find this pale green hue becomes more and more frequent until we get bed after bed of the same tint. These are known as the tea green marls, and they are just the colour of the pale green tea which used to be mixed with the ordinary black variety.

They are overlaid by a thin black stratum which is not easy to find. Its dark grains and particles fill up the cracked surface of the underlying marl, and indicate a complete change of conditions. The red and green marls may be searched for years without yielding a fragment of a fossil, but this thin black bed is full of little bright black points which a pocket lens reveals to be the teeth and spines of

fish. Diligent search usually results in the discovery of fragments of bones, and even unbroken specimens. This is the famous bone bed, and it marks the beginning of the end of the great salt lake.

The beds which lie above it alternate in colour, white, grey, and buff beds, chiefly calcareous, are interspersed among black shales, and the thin greenish marls rapidly disappear. The whole series is full of fossils, and shows that while the inhospitable character of the waters made a few temporary returns, the region had now changed from an almost lifeless waste to one teeming with living things.

In the Midlands and the North of England similar rocks characterise the time, but the sands of the Bunter division contain some beds in which the grains are like fine round shot. Now this is not seen in modern sands except where they have been blown about on the surface of a desert. They are known as the Millet seed beds, and are regarded as indicating a local drying up of part of the great lake so that the sands were blown over its basin. It is worth noting that some of the sandy beds which lie just above the Heavitree breccias show a similar structure.

The water formed sandstones are often false bedded, and their surfaces are frequently rippled. Here and there they are indented by the footmarks of three-toed animals, tracks of the labyrinthodon and reptiles of the time.

The marls show sun-cracks, rain pittings, and the fossil salt crystals such as have been mentioned as occurring now and then in the marls of Sidmouth.

The series of marls, known as the Keuper, contain layers and nodules of gypsum far more extensive than anything which can be seen in Devon. Indeed, we have only to go to Watchet to see the same marls literally riddled with layers and veins of gypsum, which is quarried from the cliffs. Not far from Cardiff it occurs in large blocks of solid white or mottled crystalline stone, and the same thing may be seen near Bristol.

Near Nottingham the gypsum deposits are thick enough to yield large slabs of beautifully veined stone which is then called Alabaster.

In Cheshire not only do we find gypsum in abundance, but even beds of rock salt, which have been famous for ages.

The Mendip Hills are surrounded by the red rocks. They run up the present valleys showing that those valleys, like some of the hills and vales of Devon, date back to this distant time. But the Mendip red beds are peculiar. They are coarse conglomerates in which many of the pebbles are very little worn. They consist of pieces of the Carboniferous limestone, and evidently at one time they formed the beach and broken piles of fragments, fallen from the limestone cliffs which stood up above the waters in which the red deposit was formed. But this is not all. Although there is no doubt that the fragments of stone were Carboniferous limestone they have a different composition. They are now Dolomite, which is carbonate of lime *and magnesium*. How is this to be explained? By supposing that the waters, like those of the Dead Sea and other salt lakes, contained a large quantity of compounds of magnesium in solution. The same substances mixed with salt will also explain the abundant deposits of gypsum, for all river water contains carbonate and sulphate of lime in solution. If, then, such water enters a salt lake of such a character, the whole of the lime is precipitated in the form of gypsum.

The proofs of the existence of the salt lake are then conclusive enough to satisfy the most sceptical, and there are probably few passages in the whole of geological history which can be supported by so complete a chain of evidence, or on which there is more perfect agreement among geologists.

The next step is to ask whether we can explain a state of physical geography so totally different from that of the Carboniferous forests, and equally contrasted with the times which followed.

The desert regions of to-day all owe their dryness to one, or both, of two causes. Either they are surrounded by lofty ranges of mountains, so that moisture-laden winds have to cross these barriers before they can reach the

The Red Marls near Seaton showing green bands.

Culverhole, where the Sea Green Marls and Bone Bed reach the shore.

inland basin, or they lie in a region where the winds are persistent and blow from a cool sea on to a hotter land.

Suppose a country fenced in by heights. As the air rises to surmount the obstacle it ascends into regions of diminished pressure, with the result that clouds and rain are produced. The air, deprived of this moisture, may be further cooled by contact with the cold moors and glaciers on the summits, so that it loses still more moisture. It then descends, comes under greater pressure, is compressed and heated in the process, and sweeps over the lowlands as a hot and parching blast. So dry may such a wind be, that the ancient Peruvians used to make mummies of their dead by simply leaving the bodies to be dried by the winds from the Cordilleras of the Andes.

An example of the second type of desert is afforded by the Sahara. The prevailing wind blows from over the comparatively cool waters of the Mediterranean on to the warm soil of North Africa. It is, therefore, heated in the process, and, unless this is counteracted by a rise over high land, the air only becomes able to take up more moisture, and so grows drier and drier, since the dryness of the air does not depend on the quantity of moisture it contains, but upon what fraction that is of the greatest quantity it could contain at its particular temperature.

Now the great lake basin, which has been described, lay in the angle between two mountain chains, by which it was sheltered from all directions except the north-east, and it is quite possible that other ranges parallel to the Pennine ridge existed where the North Sea now lies. The lower and older chain in the north-west was probably still backed by an extensive area of land, but however that may have been, the ranges themselves would have been enough to rob winds from that direction of much of their moisture.

The southern chain would be an effective barrier on the south, and the two must have met somewhere south of Ireland.

The region thus penned in was open, if open at all, only towards a direction from which the winds would be cool, and from which they would have travelled far over

a continental land which extended northwards from the Hartz Mountains.

All this part of the world lies in a latitude where the normal winds are more or less from the west. They may have been varied by a seasonal change like the winds of Manchuria and Southern Asia, but any rain-bearing wind must come from the ocean, and at the time of the desert climate this lay far away on the southern side of the Hercynian chain.

It seems, then, that the dryness of Permian and Triassic time was a necessary consequence of the geography. The rainy seasons were produced by a seasonal occurrence of warm winds from the southern sea, which brought brief heavy rains, not only on the seaward slopes of the mountains, but even on to their northern sides, just as the south-west monsoon brings snow and rain on to the northern slopes of the Himalayas.

During Permian and Bunter time these rains and snows varied in frequency and amount. Some years they hardly came at all, while at other times the rivers descending into the inland basin were large and swift.

But as time went on the mountain barrier was worn lower and lower, and subsidence helped to make breaches in the southern heights. The volume of the rivers increased and the great lake spread further and further over the plains.

A large district comprising the British Islands, and a large part of Western Europe must have slowly subsided until it formed a region lower than the level of the ocean. The desert conditions seem to have extended from Great Britain to the Hartz, and from Sweden to the north of Spain, but Western Germany, and the British area apparently formed a single depression whose deepest hollows held the salt lakes.

The great ocean lay over Switzerland and Eastern Europe, and occupied a large part of what is now Asia.

Finally the breach opened wide, and in some time of storm and high tide the waters of the sea broke through the neck of land and rushed into the inland basin, carrying with them the living things with which the ocean swarmed.

Now our Keuper Lake was so large that although it was on the whole far salter than the open sea, it is quite possible that the saltness of its different gulfs varied as much as is the case in the modern Caspian. This is indicated by the occurrence of a few species of shells and fish in the red marls of Warwickshire, which are associated with remains of plants. Probably they lived near the mouth of a large river which entered the lake from the north-east, and were unable to spread into the salter waters elsewhere.

The bone bed is found not only in Britain, but also in a similar position on top of the sediments of the salt lakes of Hanover and Western Germany. There seems no reasonable doubt that it marks the first irruption of the sea; and it is usually explained as composed of the remains of the animals which inhabited the lake, and which were unable to survive in the fresher sea water. But it seems much more reasonable to assume that the fish and other creatures, which must have been killed in millions, were really those brought in with the ocean water and poisoned by the salt and bitter fluid with which it mixed. This is indicated very plainly by the fact that the remains are almost entirely those of animals which would swim freely in the water, or which might have been swept from the shores by the invading flood.

The first irruption would be brief, but, as subsidence went on another and another would follow, until at last the salt lake of Keuper times became only a great arm of the sea like the Baltic or the Persian Gulf, and the silent shores of the great Dead Sea awoke to a new world and new forms of life.

CHAPTER IX.

The Age of Reptiles.

The geographical revolution which closed the Triassic period was hardly less important than the great upheaval of early Permian times. Although the earth movements which produced it were comparatively trifling, their effect was to bring about a complete change of climate, and so to utterly alter the aspect of the country. Instead of an arid desert, with salt and bitter lakes, in which few creatures lived, the land was covered with forests; rivers and streams came tumbling down the slopes; and the long sheet of water which covered a considerable part of the British area had become a great arm of the ocean, swarming with living things.

The change was not brought about suddenly. When the sea first entered the inland basin, and the rainfall became abundant, the whole region must have been covered by the debris due to desert erosion. If we read a description of the Sahara, or the great Asiatic deserts, we can form an idea of the state in which the country must have been. Accumulations of desert-blown sand and dust must have filled up many of the valleys, and great screes of broken rubbish must have strewn the slopes.

When the climate changed, these deposits must have rapidly crumbled away, filling the streams with a heavy load of mud. The desert soil, when properly watered, must have been rapidly covered with luxuriant vegetation, which would help further disintegration; and would also, by reducing the compounds of iron change the colour of the muds to shades of green or black. Large districts must have been composed of disintegrated coal measures, while many of the higher hills and peaks were crags of Carboniferous Limestone, and over the Channel the heights of the western part of the Hercynian chain were made of Devonian sandstones, grits, and limestone.

It is only in the extreme east of Devon that we can now see anything of the sediments which formed under

these new conditions, so, if we would know the story of the country during the time, we must go to this eastern end, and must also go much further afield.

The grey green marls which end the deposits of the Keuper Lake have already been described as showing themselves with their bone bed cap at Culverhole, under the Bindon Cliffs. This is just at the beginning of the great landslip, and the exact order of the overlying beds is not clearly seen. But a few yards further east there is a low cliff of blue black shales, covered by some impure cream-coloured limestones. Both are fossiliferous, and the black shales are, in places, almost made up of broken shells, or rather of layers of mud shewing the impressions of shells which have themselves disappeared.

A better section is afforded by the cliffs in Charton Bay, just beyond the spot where the private road from Rousdon reaches the shore. Here the upper part of the Trias is well shown in the cliffs. The beds are bent into a low arch, or anticline, so, as we move eastwards, higher beds come down to the beach. Above the low cliff the land slopes up, terrace upon terrace, and if we clamber up them we can see a fine section of the upper beds. Black and dark grey shales alternate with thin seams of impure limestone, which get whiter and more frequent as we get higher in the series, until we reach a group of pale cream-coloured limestones which are separated from each other only by thin layers of white or pale grey marl. These are the White Lias, as they have long been called, and they mark the end of the transition period.

From the bone bed to the top of the White Lias we have the local representatives of a series which is known as the Rhaetic beds. They form a good example of what are known as passage beds, which means that they were formed in a time of rapid geographical change, and are a connecting link between two much more extensive series formed under more stable climatic conditions. Below them we have the Trias, with its record of long continued desert conditions; above them we have the Lias, with its tale of the narrow seas and exuberant life.

Still higher up the cliff slopes, above the bay, we meet with the lower part of the Blue Lias, with its beds of blue grey clay and shale and thin bedded grey limestone.

The name Lias is supposed to have been derived from the way in which the quarrymen have been in the habit of pronouncing the word layers, a descriptive name for the kind of stone. Lias limestone has long been worked, both as a building stone and for the making of lime. For the latter purpose it has certain special advantages. It burns white, giving a white lime which sets into concrete and plaster almost as well as Portland Cement, and it is a frequent stipulation in building contracts that no lime but Lias lime may be used.

There is a disused road track from the Rousdon Waterworks, which slopes gradually down to the shore at Charton Bay. Here we can see the Lower Lias, and first meet with abundant traces of its rich variety of fossils. We can see also, very well, the characteristic arrangement of the deposits in alternating layers of shaly clay and limestone.

In some places where large blocks of the shale have partly dried, they split up on exposure to the weather into thin sheets which suggest the idea of sheets of thick paper or rotten millboard. They are well-known as the paper shales, and of course the sheets are the separate laminae, each plane of division marking a brief pause in deposition.

To see the Lias to the best advantage, we must go just over the county border into Dorset and descend to the shore at Pinhay Bay. Here, at low water, we can find the same black fossiliferous shales laid bare upon the beach. In the base of the cliff we have the white Lias, and forming the cliff all the way to Lyme Regis there is a splendid section of the Lower Lias.

Along the shore, embedded in the rocky ledges, we can see frequent examples of a great Nautilus, Ammonites of various sizes up to two feet or more in diameter, various other molluscs, pieces of fossil drift wood, and now and then the bones and vertebrae of great Saurians.

Beyond Lyme, along the coast towards Charmouth, the same, and still higher, beds of the same great series may be

The West Cliff, Lyme Regis.

The Church Cliffs, Lyme Regis.

seen. The Church Cliffs, just east of Lyme, probably give the most typical section of the limestone layers. Further east the clays become more and more predominant, until the limestones are comparatively few and far between. Indeed, although the limestones are best known from their commercial value, the Lias as a whole is a great clay formation, and the sea in which it was deposited must have been generally muddy.

Exactly similar rocks are to be seen on the coasts of the Bristol Channel, and in some places near Watchet fossils are much more easily found than they are at Lyme. Beginners in geology who are in the acute fossil hunting stage are generally disappointed on first visiting the Dorset coast. The fossils have to be looked for carefully. But here and there on the coast of the Bristol Channel they are to be seen by the hundred. Again, the Lyme Regis fossils are often embedded in the hard limestone, from which it is by no means easy to free them, while near Watchet they are shown on the surfaces of the shales, and may be easily secured.

It is in the Lias that we first, in Britain, meet with the order of Ammonites, fossils which are a joy to the beginner from their abundance and beauty, and also to the specialist, who, revelling in the minute distinctions between their different species and genera, changes their names every few years. This pastime of the specialist is at the same time the despair of the student, who finds himself face to face with the necessity of re-learning the generic names periodically. To the field geologist, who need not trouble himself about names, they are an invaluable guide to the age of almost any secondary rock; for it is probable that in the whole range of marine organisms no other order can compare with the Ammonites for mutability. Genus after genus, and species after species, seems to have come into existence, to have rapidly multiplied, and then to have disappeared for ever, while its place was taken by some different form.

For instance, while the bottom beds of the Blue Lias were being formed, the sea swarmed with one Ammonite, whose specific name is *Planorbe* or *Planorbis*. Its place

was then taken by another called *Angulatus*, and it in turn gave way to a third which is known as *Bucklandi*. We therefore speak of the Planorbis Zone, the Bucklandi Zone, and so forth; and when we find Planorbis in Pinhay Bay, we know that the beds in which it occurs are of the same age as those between Blue Anchor and Watchet, in which Planorbis may be seen in thousands.

The whole of the Lias is thus divided up into seventeen zones, each named after its typical fossil. In later deposits of the Mesozoic or Secondary Era other orders are pressed into service for a similar purpose, and we shall meet with several examples later on.

In Liassic time the dominant forms of life were reptiles, and, while some were not unlike a modern representative of the class, there were large numbers of others of the most extraordinary types. Best known among these is the Ichthyosaurus, a voracious carnivorous creature, which had the body of a porpoise, provided with a great vertical tail and four powerful paddles in place of the ordinary reptilian limbs. A powerful swimmer, it must have caught its prey by sheer speed, and its great jaws and teeth showed that it lived on large animals. Next in order of familiarity was the Plesiosaurus. It also was adapted for a marine life, but it had a long thin neck which was probably as stiff as that of a giraffe, its paddles were of a feebler build, and in its habits it was probably a vegetable feeder.

But most remarkable of all were the Pterodactyles. Their front limbs were greatly modified, so that they served to support long membranous wings, by which the creatures flew from place to place like birds. Most of them were small in Liassic time, and they probably fed on the insects, dragon-flies and beetles, etc., whose remains are often found entombed along with the bones of the Pterodactyles.

Truly the world must have been a strange place, and if space allowed it would be easy to write whole chapters on its Liassic inhabitants, but although these creatures were some of them Devonians, they were but a passing phase of life, the population of the country for a time, and they are briefly mentioned only as indicating the kind of climate.

Ideal Restoration of Liassic Geography.

Full descriptions of the fossils and excellent restorations of their living forms must be sought elsewhere.*

The Liassic Sea, we remember, was formed by the admission of the open waters to the inland basin by a gentle subsidence in a south-eastern direction, towards Germany. The question then presents itself as to how far it extended over the British area, and what part did the Liassic clays and limestones play in modifying the pre-existent scenery.

If reference is made to the ideal map of the red breccia period† the Permian lakes will be seen occupying the lowest parts of the inland basin. From the southern lake long valleys run westward over central Devon, between Exmoor and the Quantocks, and along the Bristol Channel. Lowlands are found in the English midlands, over the Irish Sea and Antrim, and stretching northwards along the North Channel and the western Isles of Scotland. Here the plains are part of the basin of Lake Caledonia, and a little further north they expand again over the basin of Lake Lorne.

Now as the waters of the Keuper Lake rose higher, they spread further and further over these flatter districts, and the probable margin of the water can be easily traced. Mr. Jukes-Browne has shown‡ that the Keuper Lake extended far beyond the limits of the Permian sheets of water, and that two detached lakes lay in the northern basin which were probably fresh. One of these occupied part of the site of the Old Red Sandstone Lake Orcadie, while the other lay where the Minch is now.

It has already been said that the influx of ocean water was to a great extent brought about by a subsidence of part of the long Hercynian chain. This is shown by the distribution of Liassic rocks in Europe, and in attempting a geographical restoration, we must represent this by supposing that the eastern end of the English Channel became filled with water. It seems likely, however, that some of the ranges of hills would still project as long narrow islands.

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* *Extinct Monsters*, by Hutchinson, and *Dragons of the Air*, by H. G. Seeley.

† Page 62.

‡ *Building of the British Isles*, p. 130.

The shore line all along the Eastern counties is exceedingly problematical, and the same is true of the line east of Yorkshire. There is no doubt however that it was not very far away, from the frequent occurence of plant remains.

The main arm of the sea extended over Cheshire and Lancashire, over the basin of the Irish Sea, and far up the western shores of Scotland. Gulfs extended almost around the Cumbrian mountains, which stood out as a hilly promontory, others ran up the Clyde far enough to cover the Isle of Arran, and over the islands of Skye, Mull, and Raasay, and finally up the Minch, and along the line of the Caledonian Canal into the basin of Lake Orcadie.

It is interesting to note how the old structural features dating from the Protozoic upheaval, again asserted themselves after so vast a lapse of time. The basin of the southern Lake Caledonia seems only to have been refilled in its south-western part : probably because the portion which extended across Scotland was blocked by the products of the Volcanic episodes of Carboniferous and Permian time.

The western shore extended along the border counties of England and Wales, and it is not likely that it ever extended many miles further west than the Permian breccias. They were certainly accumulated at the feet of steep slopes and many of them were most likely mountain screes rising steeply out of the water of the lakes. When the level rose with the progress of Triassic time it is not likely that the water made much advance into the mountain regions of Wales and Devon except that it would run a little further up the valleys, forming long narrow lochs. The same must have been true of the Liassic Sea. Quite a moderate rise of level might well account for such changes as we have described, and a change of a hundred feet or so would not greatly alter the coastline of a mountainous shore.

It is certain however that the lower Lias did extend up the valley of the Bristol Channel, and it is probable, therefore, that it also extended up the valley of central Devon, but we have nothing left to suggest its former presence above the breccias. There is one piece of evidence which points to a westward extension further

south, and that is an observation by Mr. R. N. Worth, of Liassic fragments in an ancient gravel near Plymouth,* but if we picture the probable contours of the country it seems more likely that these fragments came from some southern fjord of the Liassic Sea than from the north, and it is thus suggested in our ideal restoration.

The Liassic limestones are themselves rather puzzling, and their mode of occurrence is especially difficult to understand. The Silurian limestones were evidently due to organic accumulations in clear water. The Devonian limestones we have also attributed to the agency of corals and other reef building organisms. The massive limestones of Carboniferous times were again mainly organic. What then about the Lias? Does each thin band of limestone mean clear water, and the growth of calcareous organisms? If so, we should expect such beds to dwindle away as we approach the ancient shores, and should look for evidence of an organic origin in the stone itself. As a matter of fact, the limestones become more prominent as we near the old shore, and the beds give very scanty indication of an organic origin. We are forced to the conclusion that the Lias limestones are formed from calcareous mud derived from the wide extent of Carboniferous and Devonian limestone, which was certainly laid bare upon the hills and mountains around.

But this conclusion by no means ends the difficulty. If we look at the Church Cliffs of Lyme, and consider their regular alternations, we may well ask why the mud should sometimes have been nearly all calcareous, and why at other times it should have been ordinary clay; and again, does the alternation record mere oscillations of weather according to the seasons, or do the recurrent changes point to the sun spot cycle, or some other periodic change? These are questions which cannot be answered with any confidence, though we may make suggestions that they are due to changes of rainfall, and that most likely the limestone mud came when certain rivers were in flood, the ordinary muds when others were full.

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* *Quart Jour. Geol. Soc.*, 1889, p. 401.

Important as the Lias is, it formed only the first phase in a long series of changes. We find that the great clay deposits are covered by an equally large and important series of cream-coloured limestones which abound in proofs of their organic origin. These are the lower or Bath Oolites, which may be studied all along the district from Bath to Cheltenham, and across England to the Yorkshire coast. For some reason or another the muds were shut off from the greater part of the sea floor, which became covered with banks of shells and coral reefs, and layers of calcareous sand and mud derived from their waste.

The change is so rapid that it looks as if some earth movements must have come into play, which lessened the declivities down which the rivers flowed, and probably also resulted into converting some parts of their valleys into lakes where their mud could be dropped, leaving the water as clear as that of the Rhone when it issues from the lake of Geneva. If we suppose that the great western continent began to subside at this time, we have the explanation we want, especially if we remember that there was little or no change in the coastline of Devon and Wales. The amount of subsidence necessary would be small, for apart from the suddeness with which the final change took place we should expect that the quantity of mud available for deposit would rapidly lessen as the covering of loose decomposed materials formed in the desert period was denuded away, and the harder solid rock brought next the soil.

The northern parts of the Liassic basin became the sites of estuarine deposits, and in Yorkshire even seams of coal were formed over swamps, which were probably the delta of a large river coming from the east, or north-east.

Somewhat similar evidences of a lessening of the sea are to be found on the West of Scotland and in the Midlands, while, on the contrary, under London the Oolites spread over the Devonian ridges which had stood up above the waves of the Liassic Sea, and a similar overlap on to older rocks may be found at the eastern end of the Mendips close to Frome.

At present the most western bits of the lower Oolites are at Ilminster, Crewkerne, Beaminster, and Bridport, but although they do not at any of those places bear any signs of a special approach to land, there is no reason for supposing that they ever extended far into Devon. If they did they have been totally removed, and the only part they can have borne in the building of our scenery must have been a temporary delay in the waste of the underlying rocks.

Again the sea deepened, the rivers became laden with mud, and the shell-strewn coral reefs were buried in a great clay deposit called the Oxford clay, which spread over the whole region once occupied by the Liassic Sea, except, perhaps, its south-western borders. It is well shown in the dark blue clays close to Weymouth, where it may be easily seen and its fossil contents compared with those of the Lyme Regis cliffs.

This is again overlaid by massive coral banks which must have swarmed with sea urchins and shell fish. Evidently the clear water conditions had returned, and the modified descendants of the sea creatures, which had built up the Bath Oolites, returned to the haunts of their forefathers. The Corallian series, as it is called from the multitude of corals, is fairly thick in Dorset, but grows thinner northwards by Oxford and then thickens again in Yorkshire, an early indication of the formation of a ridge which would later on separate the south-eastern sea from that of the Yorkshire coast. This is another example of the long persistence of a physical feature, for it really dates back at least to that partial division of the carboniferous sea by a midland ridge to which we referred in an earlier chapter.* The clearance, however, was only for a time. The Corallian series is covered in turn by yet another great clay deposit known as the Kimeridge clay, which extends from Dorsetshire to Yorkshire.

This is a formation of great interest, and probably marks the period at which this part of the world possessed

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*Page 43.

a richer variety of reptilian life than at any other. Ichthyosaurs, Plesiosaurs, and Pterodactyles were abundant, and their remains are mixed with those of Tortoises, Crocodiles, and many representatives of a group called the Deinosaurs. This last included some of the most uncanny, and some of the largest animals which ever trod the earth. Some of them were herbivorous, others carnivorous. Some went on all fours, while others used the forelegs only for holding or fighting, being in the habit of getting about by walking on the hinder pair.

The oscillations of the whole region which brought the alternations from clay to coral and back again to clay were beginning to near their end. The Kimeridge clay does not cover the whole basin of the Lias Sea, but is very thick at its eastern end, where a boring put down in Sussex passed through it for 1,000 feet. The earth movements had not ceased, they had changed into a general uplift of the northern and western parts of Britain, accompanied by a steady shift of the coast-line towards the south-east.

The rivers which had flowed from the north western continent into the marine gulf of earlier Jurassic time now had to find their way across the gentle undulating plains laid bare by the retreat of the sea; and for a time they discharged themselves into a steadily shrinking region over the counties of Dorsetshire and Wiltshire.

In the shallow seas a series of sands and limestones were formed, somewhat resembling the Bath Oolite, but greyer in colour. Some of them are the excellent building stone so largely quarried at Portland, while others are entirely built of shells, or of the calcareous mud in which they were embedded. One great bed is very curious; it is known in Portland as the "Roach," and lies just above the best stone, so that, although it can only be used for rough building purposes, it has to be quarried away to get at the under layer. Evidently a vast accumulation of shells had gathered on the sea floor, and all the interstices between and within them had been filled in with calcareous mud. Then, for some strange reason, the whole of the original shells were dissolved away, leaving perfect hollow casts of their external

form, and in each hollow an equally perfect cast of the shell's interior. The Cobb at Lyme is built of this stone, and its peculiar structure may be seen there, though, of course, it can be better studied at Portland.

These shallow water marine beds could not accumulate greatly without still further diminishing the area of sea. Shell banks arose above the water, and the river-borne materials helped to fill in the deeper parts, until the open water was pushed further and further south and east.

Where the shallows became low lying islands soils were formed upon them, and the forests spread from the neighbouring shores. In the pools between these islets sands and mud and beds of limestone composed of freshwater shells accumulated. Then came a further small subsidence and inroad of the sea, only to be followed by a second silting up of the whole district.

Thus it was that the Kimeridge clay was covered by the Portland series, and it in turn by the mixed freshwater, estuarine and marine beds of the Purbeck time, so called from their development in the isle of Purbeck.

Some of these fresh-water limestones are full of the remains of insects, some of them are entirely composed of shells of genera whose modern representatives are only found in fresh water. For instance, the so-called Purbeck Marble is a hard limestone, wholly made of little snail-shells of a fresh-water genus Paludina. The stone takes a high polish, and the "figure" of its markings is due to the sections of the shells. Excellent examples may be seen in the slender shafts which make the great pillars of Exeter Cathedral.

The old soils are particularly interesting. In some of the Portland quarries one of two of the Purbeck "dirt beds" lie above the stone, and in the course of the quarrying operations extensive areas of dirt bed are sometimes uncovered. When this is the case it is possible to walk on the ancient land surface, to see the stumps of the forest trees (now completely converted into silica) in the position of growth, with their roots branching downwards into the soil. Other broken bits of the fallen trees lie about half

buried in the soil, and though there is no vestige of woody material left, the minutest details of its structure are preserved in the stony substance by which it has been replaced.

The Purbeck beds give us the last glimpses of the retreating sea, and at length it was pushed almost away from Britain, leaving only a narrow area from Swanage to Sussex, which formed a hollow which was rapidly silting up.

Here the Purbeck limestone series passes gradually upwards into a great mass of sands and clays which are all of fresh water origin. An important change had taken place somewhat gradually, and is indicated by the deposit of the coarser detrital material on top of the locally formed shell banks. The carrying power of the rivers had been increased by a further uplift of their upper reaches, whereby the slopes down which they flowed were made a little steeper.

A great river discharged itself not far from the position of the Isle of Wight, and at low water, on the western coast, the local guides point out a "submerged forest." It is nothing of the sort, but is a vast raft of tangled tree trunks which was stranded on the shallows of the river delta after some violent flood, just as we find similar rafts borne down the great rivers of to-day.

Sandy beds full of Paludinae occur, and detached bits of driftwood, fossil ferns, and other plants, and bones of some of the great Deinosaurs are characteristic of the whole deposit.

Beds of this character spread over the area of the Weald of Kent and Sussex, so the period is often spoken of as the Wealden. The cliffs of Hastings give fine sections of some of its beds, and at low water, when the original surfaces of the strata are laid bare, it is no uncommon thing to find the huge footprints of Deinosaurs, showing the tracks they made as they wandered over the sandy flats and shallows in search of food. One footprint, a cast of which shows the wrinkles on the creature's skin, is preserved in the Hastings Museum. It measures about twenty inches in length.

It is a question whether the Wealden deposits are a delta such as that of the Mississippi, or whether they are

not more probably river-borne deposits collected in a large lake. But this is a matter which has little bearing on our main purpose, which is to trace the changes of time in their bearing on our western shires.

In this brief account of Liassic and Jurassic days we have seen the coast line pushed far away from the western hills until they stood up far away in the interior of a great continent. It is almost certain that the English Channel was represented between Devon and Brittany only by the valley of a river or rivers flowing eastwards. Indeed, the drainage system of the whole region was probably towards the south-east, though we have no evidence to show how far further west lay the edge of any possible Atlantic.

Devon had all this time been undergoing the wear and tear of time. When we consider the vast quantity of sand and mud which must have been required to make up the Bunter sands, the Keuper marls, the clays and limestones of the Lias, and the great deposits of the Oxford and Kimeridge clay, and then reflect that this had all been worn away from the neighbouring land, it becomes evident that a vast amount of erosion must have taken place.

What wonder, then, that we have felt justified in speaking of Dartmoor in Permian days as lying far above the present surface. And the whole length of Jurassic time was only a small step from then to now.

Here, then, we may picture our western hills as mountain summits overlooking a wide plain which stretched eastwards to the Solent and beyond. Across this plain great rivers wended their slow courses to the distant swamps, meandering through jungles and forests something like those in the best watered parts of tropical Australia, for the vegetation of the time and even some of the animals were not very much unlike those of the great island continent to-day; for in spite of the huge reptiles, which have long vanished, the world was beginning to assume a guise far nearer to its present state. Many of its simpler organisms, and even some of its higher plants and animals, were beginning to resemble those which we now can find pushed away into the far corners of the world.

CHAPTER X.

The Return of the Sea.

We have no means by which we can estimate, except by the roughest comparisons, the lapse of time during any geological period. We cannot say, therefore, for how many years the rivers of Southern Britain flowed into the Wealden Lake. All we can feel certain about is that their number would be expressed by many figures.

The broad plains left dry, as the waves retreated during the closing phases of Jurassic time, must have been acted on, like any other country, by the streams which crossed them. Wherever the Keuper marls, or any part of the great clay deposits formed the surface, erosion must have been rapid and the valleys must have opened wide, forming a landscape of gentle slopes and level stretches. Where, on the other hand, the harder limestones came to the surface, the rivers would have deepened their channels faster than the valley slopes were worn away, with the result of deep valleys flanked by steep slopes such as those we find round Bath and Bristol at the present day.

The western edges of the limestones must then have formed lines of hills as they do now, but these escarpments, as they would be called, must have been further west than the modern hills. Moreover, as the drainage of the whole country was certainly towards the south and east, we can picture a great river following the line of the Liassic Sea, and gathering together as its tributaries those which had flowed from the western and northern highlands. Others further south flowed from the mountains of Wales and Devon, and probably from further west, perhaps even so far as Ireland, and these, in following up the retreating shore, must have cut across ridge after ridge.

The fact that the upraised bed of the old inland sea was thus necessarily converted into an undulating country, with lines of hills at different heights and with varying slopes, is a point which will have to be remembered later on.

It is also well to point out that nothing which we have yet mentioned in the history of Jurassic time would have been likely to alter substantially the lines of mountain and valley in any part of the western districts. They would still be those mapped out during the post-carboniferous upheaval, only slightly modified here and there by volcanic outpourings, and by the slow changes due to river erosion.

During the continental period the newer sediments were from time to time shaken by earthquakes, and the rocks were traversed by lines of fracture accompanied by vertical movements. But such changes do not often result in any marked alteration in the geography of the country affected. Sometimes they modify some of the minor features of the drainage system, but their results are soon smoothed away, unless they are much more considerable than any disturbance which can be shown to have affected the rocks during Jurassic and Wealden times. That they did occur can be clearly seen in the frequent faults which cut through the Jurassic and earlier strata and do not penetrate those which lie above. Many of these can be seen in the Keuper marls of the Devonshire coast. They are probably due to the slow shrinking and consolidation of the underlying materials, and are quite a different thing from the thrusts and flexures caused by the throes of mountain building.

However long the continental period may have been, at length its end was reached, and a wide-spread subsidence set in, accompanied by a steady return of the open sea. Everywhere where the top of the Wealden can be seen, it passes upwards into a great series of sands and clays which contain abundant marine organisms. Some of these beds are dark green in colour, from the presence of large quantities of a deep green mineral called Glauconite. These green sands are sometimes so conspicuous that they have given the name of Lower Greensand to the whole series. The name is unfortunate, as the bulk of the deposits are coloured shades of yellow and brown, the distinct green hue being restricted to a few beds.

The Lower Greensand may be studied very well in the Isle of Wight, either in the coast southwards from Shanklin,

or at the south-western corner of the island, by Blackgang Chine.

Its beds may be seen also all round the Weald of Kent and Sussex, where they form a line of lofty wooded hills standing out in front of the smooth rounded heights of the North and South Downs.

The change having been due to a subsidence, it naturally follows that the marine Lower Greensand spreads over a larger area than the underlying Wealden. At present it does not extend further west than the Isle of Purbeck, and northwards it reaches into Berkshire, where it assumes a peculiar shore-like form. Its beds are there filled with fragments and pebbles of Jurassic rocks, mixed with shells and fossil sponges in such a way as to show that it consists partly of the debris of the old land made by the waves as they advanced.

Step by step the general change of level continued, and we find the Lower Greensand buried under a formation which, in the south-east of England is a thick clay, so fine grained that many of its fossils still show their pearly lustre, like some of the Ammonites of the Lower Lias clays of Blue Anchor.

No doubt the old Jurassic clays were being used over again after yet another process of disintegration and decay.

As this south-eastern clay, called the Gault, is traced across the country towards the west, its character changes. Sandy particles become mixed with it. They become more and more numerous, and when we enter Devon it is all sandy.

High up the terraced slopes of Black Venn, near Lyme Regis, the Gault clay is represented by a few feet of dark greenish grey stuff, half sand, half clay, in which badly preserved fossils are numerous. The new Survey Map shews it again in the cutting at the eastern end of the Honiton tunnel, and exactly similar material, causing a patch of marshy ground and the outbursts of springs, occurs at the foot of the White Cliff, by the bathing cove at Seaton, and in several places in the Axmouth landslip.

Now the fact that it occurs only here and there over these western counties is highly suggestive. If present in

the Honiton cutting why does it not occur in many places in the neighbourhood. There are miles and miles around where the underlying and overlying rocks are to be seen, but, so far, it is only in the one spot that any representative of the Gault clay has been identified. Everywhere else it is apparently missed out.

At Black Venn the Gault lies on the eroded surface of the Lower Lias; at the Honiton cutting it is on a similarly worn surface of Triassic Marl. At Seaton the dark sandy clay also reposes on denuded Triassic Marl.

The explanation is doubtless to be found in the fact that the surface upon which it rests is the old land surface.

We have pointed out that this must have been diversified by hill and dale, and as the sea advanced, unless that advance was so exceedingly slow that the waves could entirely plane away all projections (which is almost out of the question), it must have flowed up the valleys first. From them it would rise gradually over the intervening watersheds, and when it had finally overtopped them the contour of its bottom would still preserve a sort of fainter copy of the contours of the submerged land.

If then we suppose that in such places as the Honiton tunnel, and possibly the White Cliff of Seaton, we have relics of a submerged valley, we have a complete solution of the mystery, for the Gault clay of one place is but the deeper water representative of the sandy clay of other places where the depth was less, or of the sands still nearer shore.

The Gault clay is in turn generally overlaid by a series of sands and Chert beds, which, as a whole, are much paler in colour than the Lower Greensand, but exhibit a green tinge in some of the beds. This is commonly known as the Upper Greensand.

A fine typical section of the whole formation as it is found in the east of Devon may be seen in the White Cliff at Seaton.

If we go westwards from the town along the path under the cliffs we get a fine view of the general structure of the section. On reaching the corner it is well to follow the path as it ascends to the road. On reaching this there

is a sharp turn to the left, which leads in a few yards to the cliff, where there is a seat looking down on the bathing cove. Here we command a splendid view of the details of the Greensand.

The base of the cliff is a dark sandy clay which makes a patch of wet ground thickly clothed with reeds, mare's tails and moss. Above this is a much thicker stratum of greenish sands which make a moderate slope covered here and there with small potato fields. The face of the cliff then becomes vertical, and is formed of greenish sands cut up into layers of about two or three feet in thickness by broken lines of harder stone locally known as cowstones, These stand out from the rest and fall down to the beach as the softer intervening sand is worn away. In our illustration of Culverhole the great majority of the large flattish stones with which the beach is covered are wave-worn cowstones.

Above these there is a stratum of yellow sand capped by rusty weathered cherts which, when seen from a distance stand out very conspicuously as a ruddy band. This is the bottom part of a great series of chert beds separated by rather thin bands of sand. The part of the cliff where they form the face is very rough and rugged. The soft intervening sands are worn away by frost, and rain, and wind, while the hard cherts stand out as projecting shelves on which seagulls and jackdaws make their nests.

The Cherts are covered by a thin band of very bright green sand. It cannot be well distinguished in the main section of the cliff, but is best identified by clambering over the rocks below till we get near to the point which forms the eastern end of Beer Cove. Here the top of the greensand comes down to the beach, and its uppermost beds may be studied in detail.

The green and yellowish sands below the cherts are commonly known as the Foxmould.

The same strata are exposed in the cliffs all along the great landslips from the Haven Cliff on the eastern side of the Axe to Lyme Regis, and they may be examined in the broken fragments of the undercliff, or on the beach. In the

Haven Cliff and along the shore to Culverhole, they may be seen resting on an eroded surface of the Keuper marls, which show numbers of small faults and undulations, not one of which passes up into the Greensand beds above.

At the Landslip the Greensand rests on the Rhaetics and near Rousdon on the Lias.

If we go westward from Seaton, we find the whole series dips down out of sight under Beer. But it reappears on the other side of Beer Head and can be followed in a long stretch of magnificent sections through the Branscombe potato fields, under Hooken Cliff, and, resting always on the Keuper marls, all along the coast to Sidmouth, rising higher and higher above the beach as we go along the shore.

After passing Sidmouth we can still trace it forming the the cap of Peak Hill and High Peak, and underlying the surface beds of all the greater hills. The Woodbury Common ridge does not seem to have any Greensand beds in their original position, but there are extensive patches of gravels whose lower portions contain Greensand fossils in such a condition as to show that they cannot have travelled far, so we may be sure that the formation which they characterise capped that ridge also, in the days when the gravel was formed.

If we cross the broad valley of the Exe, and climb up the slopes of Haldon, we soon come upon the Greensand beds again. They crop out once more on the western face of the hill, high on the flank of the valley of the Teign, but here is the end. The greater heights of Dartmoor show no vestige of any former coat of Greensand, and it is impossible to suppose that if the chert beds had ever extended over it every trace of such an enduring rock could have been cleared away.

The Greensand sea must have ended over what is now the valley of the Teign.

The same beds can be traced all along the Haldon ridge, but with the exception of a few isolated patches far to the west, which suggest that a long fjord ran westwards along the line of the Crediton valley, and which we should

expect to find there, we have to turn eastward again to the Blackdown Hills before we can follow them northwards.

All over these hills the Lias and Trias are capped by a layer of Greensand, and along its western outcrop it assumes a peculiar form.

Some of the sandy beds contained numerous fine grained concretionary lumps which harden on exposure to the air and made excellent scythe stones. They were formerly the object of a considerable industry. Tunnels were driven in along the right layers, and great heaps of material were dug out and now lie in white scree-like slopes just below the crest of the hills.

Quantities of fossils were thus found, many of them beautifully preserved, and all marked by the fact that the calcareous matter has been wholly removed and its place taken by silica. This is noticeable also in the fossils from Haldon, and indeed generally from the Greensand of Devon.

The Blackdown beds and their fossils have been well described by the Rev. W. Downes,* whose collection of fossils may now be seen in the Museum at Exeter.

It is enough for us here to say that the species of shells, and the condition in which they are found, all point to shallow water and to a near approach to land.

Among the cherts and the harder sandstone beds, the spicules of flinty sponges are to be seen in immense abundance, so much that it is evident that the chert beds are to a great extent made up from the fusion together of such spicules.

The glauconite grains which give the greenish tinge to some of the beds are worth examining. Under a pocket lens they seem to be rounded grains of sand, but under the microscope they are to be recognised as the internal casts of the shells of foraminifera. It is interesting to know that precisely similar grains are now being formed off the coasts of Georgia and South Carolina, by the deposition of the green mineral inside minute calcareous skeletons, and in the interstices of shells.

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* *Quart. Jour. Geol. Soc.*, 1882, p. 75.

The Haven C iff, Axmouth:
Greensand on eroded surface of Keuper Marls.

The Upper Greensand extends all across England from Haldon to Yorkshire, varying a good deal in its texture and even in its materials. It has long been a subject for discussion as to how far it may strictly be regarded as a mere shallower water representative of the Gault clays. It is now generally agreed that to a great extent this is the case, at least in its lower portions, while some of its uppermost beds may very well represent other deeper water deposits which we shall meet with later on.

We have already pointed out that the country on the western shores of the old Liassic sea must still have preserved its main features. We have now shown that the Upper Greensand sea in Devon reached much the same limits. It is only reasonable therefore to suppose that its coast extended some way up the valley of the Bristol Channel and then curved eastward round the border hills and through Monmouth. From this point it crossed the old sea basin in a north-easterly direction to the eastern flank of the Pennine range, and thence followed the contours of the country to the coast of Yorkshire or Northumberland.

Now the Upper Greensand is a very different formation from the underlying Gault clay and Lower Greensands. Still more marked is the contrast between the Chert beds and the Foxmould. The latter is made largely, though not wholly, of land derived materials, whereas the Chert beds suggest a fairly clear sea into which no considerable rivers can have poured the waste of the land.

Here is a problem which evidently needs solution, and the most probable answer is that it was during Upper Greensand time that the Atlantic began to make inroads on the north-western continent, and worked northwards along our western coasts. This would mean that many of the rivers which had flowed into the Liassic Sea and had afterwards found their way to the Wealden Lake, were now turned westwards and carried their sand and mud into the western sea, while perhaps others were shortened by the deflection of their upper waters along the channel of some western tributary whose slope had been reversed.

When Gault and Greensand are traced eastwards across England they are found to pass into a red calcareous deposit called the red chalk. It is well shown in the cliffs of Hunstanton in Norfolk. As they are traced towards Dover the clay gradually forms a larger and larger portion of the whole, until at Folkestone the sands are represented only in the bottom beds.

These facts again need explanation, and a fairly satisfactory one is easily suggested.

When the waves of the sea beat upon a shore they remove its materials and spread them over the sea floor in the neighbourhood. The finer mud is carried far out to sea, while the coarser sand soon settles to the bottom. If there should happen to be a strong tidal current, or any other current, along the shore, the mud will be picked up and carried away by it, and if this mud has a peculiar colour the drift of the current must be marked out upon the sea bottom beneath.

It is only necessary to stand on the cliffs near Sidmouth, or the Church Cliffs at Lyme, when there is a heavy surf beating against their base, to see the process in full progress. The water for some distance out will be seen to be turbid with mud, forming a red fringe at Sidmouth and a grey one at Lyme.

Another fact of some importance may be seen at the Warren at the mouth of the Exe. This is an accumulation of sand, which extends from the western bank of the estuary and projects eastwards beyond Exmouth.

Now the source from which this sand is derived is certainly, in the main, the neighbouring cliffs; and the diminution of the size of the Warren in recent years is most probably to be traced to the building of the Great Western Railway walls along the foot of the cliffs most of the way to Teignmouth, whereby the supply of sand has been lessened.

The grains of sand when taken from the cliffs are deep red in colour and are often sharply angular. But that which is taken from the Warren is rounder and has very little red, resembling in colour some of the red cliff sand

which has undergone a long boiling in acid. It seems that the jostling of the grains upon the shore, and possibly to some extent the chemical action of the salts in solution, removes the skin of iron rust which colours them, rounds off their edges and even extracts the red stain from their cracks.

If, now, we picture the waves advancing over the old land, we can see that a very large part of the Gault clays may have come from wave action on the older clays of Jurassic and Liassic time; that the red chalk of Norfolk and Lincolnshire owes its redness to a similar erosion of Triassic Marls; and finally that the sands of the Upper Greensand are to a large extent the old Bunter and Permian sands ground down and cleaned, and mixed with the green ocean-formed grains of glauconite.

When at last the waves had reached the hard rocks forming the flanks of the ancient mountains, these supplies would be cut off, and the only fine mud and sand brought into the sea would have been that brought by the streams; a scanty contribution which was often insignificant in comparison with the layers of sponge spicules from myriads of siliceous sponges with which the water swarmed. Then the chert beds would be produced, but they would only appear as cherty concretions in places where the river-borne or wave-brought material was more abundant.

We should thus expect to find the sea floor of the time covered with red mud in one place, green sand in another, while chert might be slowly forming as siliceous mud elsewhere; and all might be modified in special places by river borne detritus. It is easy then to explain the great local variation of deposit.

In Devon the upper layers of sand must have been derived partly from the Permian breccias, partly from the red sands of Exmouth, but also from the debris of the Devonian hills of North and South Devon and the volcanic piles of the Dartmoor district. Wave action and rivers must both have contributed their quota, but during much of the time the water was clear.

While the Upper Greensand was forming over the British area a wide open ocean extended eastwards through Europe

and Asia, and unless there may have been a land mass where the Pacific now lies, it must have formed a girdle round the earth. Our own Upper Greensand sea was a northern gulf opening towards the east.

Now if we remember that the tidal wave in the ocean travels from east to west, and that the ebb and flow and other tidal movements are always greatest in gulfs which open wide to meet it and narrow towards their extremity, we see that our local waters must have been the site of considerable disturbance. We should expect, therefore, to find symptoms of local erosion and signs of strong currents here and there, and feel no surprise, therefore, when they are pointed out. There are numerous spots where Greensand or Gault can be shown to have experienced local erosion or rearrangement of exactly the kind which would be brought about by strong movements due to the tides. These currents would also explain the concentration of the fine red chalky mud in one district, while the sands accumulated not far away.

We can, then, with confidence picture the Devonshire area as lying on the eastern coast line of a considerable extent of land which still comprised the district which lies south of Ireland, and west of Cornwall, and extended northwards and southwards for some hundreds of miles. Dartmoor was still partly covered with its volcanic mantle, and the Exmoor heights still raised their heads into lofty points. The great hills plunged steeply down into the waters of a clear sea, clearer even than that which washes the coast of Cornwall now.

Long fjords and gulfs ran westward into the land, flanked by hard rock and paved with white sand or naked rock, while the tide ebbed and flowed even more rapidly than it does to-day on the shores of the Bristol Channel.

Great Saurians still wandered along the shores, and wide-winged Pterosaurs sailed through the air, some of them having a width of wing of 20 feet and more. But mixed with these descendants of the Liassic reptiles were other creatures which were more direct forerunners of those which were yet to come.

Strange feathered birds flitted through the forests or waded in the shallows. Birds with toothed jaws, but otherwise resembling those we might find to-day. The forests which clothed the hills had also assumed an aspect not much unlike the present. Trees like our oaks, willows, and magnolias flourished from Europe to places now far within the Arctic circle, a fact which seems to show that the climates of the world in those distant days must have been considerably warmer than they are at present.

But the Greensand was only the earlier phase of a period which reached its full development later on, a period marked off from all others in Britain and France by the formation of the unique deposit which makes the white cliffs of Albion, and from which the whole time from the Wealden till the next great change took place has been named the Cretaceous period. We mean the chalk.

CHAPTER XI.

The Chalk.

Once more let us wend our way to Seaton, and the beautiful cliff scenery of Eastern Devon. If possible, let it be early in the year, in April when the primroses are in bloom, or in May when the cliffs of Beer are purple with the blossoms of the wild sea stock, at any rate before the sunshine has reached its full power, for we shall want to clamber about the slopes of fallen debris, fully exposed to the noonday sun.

Let us start from the White Cliff where we saw the complete section of our local Greensand topped by the rugged chert beds and the line of green sand; but this time our attention must be turned to the upper part of the cliff, which is formed of the lower portion of the Devonshire Chalk.

Next above the belt of green sand there comes a band, only a few feet thick, of a cream-coloured limestone, full of fossils, and containing large numbers of rounded grains of quartz sand. It is sometimes called the Chalk with quartz grains, but is now more often known as the Cenomanian limestone.

Above this is a mass of hard chalk, full of harder lumps which contain grains of glauconite. It is often stained with yellow compounds of iron and is not always easy to distinguish at a distance from the underlying limestone.

This hard nodular chalk is covered by a much thicker and less massive series of beds, consisting of soft white chalk divided by lines of flints, and, here and there, narrow seams of marly chalk which are hollowed out by the weather. It extends to the loftiest point of the cliff.

Let us now take the footpath along the top of the cliff and follow it over the hill to Beer. As we go along, if we look eastwards, we can see the line of cliffs across the bay, with their base of Keuper marls and Rhaetics, the upper surface of which rises and falls in gentle curves, while the overlying Greensand and the Cherts and Chalk which cap the whole lie smooth and undisturbed. If the day is clear we can make out Culverhole and the great landslip, while Golden Cap and the

The White Cliff, Seaton.

Dorset coast may be seen on the horizon stretching eastwards to the faint grey line of Portland.

As we move downward into Beer we pass close by a great buttress of chalk called Annis' Knob. It is worth careful study. The rock is stuffed full of harder nodules which stand out on the surfaces exposed to the weather; but it is white chalk, very different from that which lies next above the Cenomanian limestone, and it is distinguished also by the presence of innumerable flints, often arranged in lines.

If we follow the path to the shelter just above the Cove, where the main path turns to the right towards the village, we find a track leading eastwards down to the beach. A few yards down this slope we come again upon the soft white chalk with its lines of flints, and as we look along the face of the cliff we cannot help noticing that some of them lie in regularly spaced black layers.

Low down the cliff there is an almost continuous layer of flint which lies at the base of a white band of flintless chalk, as if all its proper share of flinty matter had been concentrated at its base. This band is about 2 feet thick. Higher up are two equally conspicuous lines about 3½ feet apart, and just above them is a similar band free from flints which is about 4 feet thick. Dr. Arthur Rowe and Mr. C. Davies Sherborne, who have made an exhaustive study of the Chalk, make use of these bands in their paper on the district,* and we shall have occasion to refer to them later on as the 2 ft. and 4 ft. bands.

By walking along the beach, still towards the eastern point, we see the flint lines rising higher and higher, while stratum after stratum comes into view above the pebbles, until, when we get within a few yards of the point, the hard nodular chalk without flints makes it appearance.

The point itself is made of this hard chalk, and it forms the lower projection, which in turn is continued seaward by a reef, which is the top of the Greensand with a capping of Cenomanian limestone.

If the tide is low enough the top of the Cherts is laid bare below the pebbles, and we can see that its beds dip gently down

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* *Proc. Geol. Ass.*, Vol. XVIII, p. 1., *et seq.*

towards the sea and to the centre of the Cove. It is possible also to walk through a low natural arch drilled through the top of the Greensand and covered by the limestone and its superincumbent hard chalk, and on emerging on the eastern side we find ourselves at the foot of a vertical cliff which gives a most perfect section of the different beds. The chert layers, black and brown in colour, rise up gently, and they, and their related sands, can be studied in detail.

Returning to Beer Cove, and crossing to its western side, we find the same flooring of cherts rising out of the sea and again covered by the same beds in the same order. There is, however, one difference. The Cenomanian limestone does not rest on a *green* sand, but on a brown layer. Moreover, in the corner of the Cove, on each side of a pile of fallen blocks of nodular chalk, the Greensand forms the base of the cliff, and it is seen to be either false bedded on rather a large scale, or else the Cenomanian limestone lies on an eroded surface. There is one place where the limestone projects a foot or so beyond the crumbling surface of the sand, and its under side can be seen to be full of fossils. Indeed it is evidently mainly composed of the shells of ammonites and other organisms, mixed up with calcareous mud, and grains of quartz sand; while it rests upon what look like the eroded edges of layers of ruddy brown sand, with numbers of green glauconite grains throughout their mass.

All along the line of cliffs which run out towards Beer Head we can trace the same divisions. There is a shelf of waveworn Greensand projecting from the base of the cliff, and above it lie the limestone, flintless chalk, and white chalk, in their proper order, and the same lines of flints can be followed winding as parallel markings from point to point.

On the western side of Beer Head the same divisions are to be traced, but if measurements are taken of the thickness of each they will be found to differ considerably from those taken at the White Cliff. But more important changes soon become evident. The great cliff under the Coastguard station on Beer Common gives another fine section. It is known as Hooken Cliff, while the slipped portion which broke away from the main mass in the year 1789 is called Under Hooken.

Beer Cove: Cenomanian Limestone on Greensand.

Beer Cove: Cenomanian Limestone on eroded Greensand.

Hooken Cliff and Under Hooken.

There is a beautiful walk here along the sloping undercliff through the little fields where early young potatoes are raised in quantities. Tall pinnacles of fallen blocks stand out above the greensward of Under Hooken, and in these we can examine the different beds at our leisure, while Hooken Cliff itself gives a diagram of the whole. All the beds shown at Beer are to be made out easily. There is the Cenomanian limestone lying just below the black entrance to some old quarry workings which have been cut into the hard flintless chalk, and above these are the same strong lines of flint with their bands of marly chalk. The 2 foot band is rather more than half way up the cliff, while the 4 foot band frequently disappears under the grass of the slopes which come down from the top.

If we follow the path which leads westwards through Under Hooken, it brings us down almost to the beach. Here we come to a stile, and just beyond is a short sloping track to the shingle. But the main path keeps on by the top of the low cliff winding along by the potato fields. About a hundred yards brings us to a large mass of rock perched on the edge above the shore, and the path winds on its landward side. This is Martin's Rock and if we turn and look at the inland cliff, which towers above us, we can make out an important change. The 2 foot band of flintless chalk rests almost immediately upon the Greensand.

The Cenomanian limestone, then the hard nodular chalk, and then the lower part of the flinty chalk have thinned out and disappeared. We have before us a sandbank of the sea in which those beds were laid down. We say a sandbank, for the disappearance is only local, as the missing beds reappear on the other side of the Branscombe Valley, capping the loftier hills for some miles further.

In the last chapter the Greensand was followed past Sidmouth and Woodbury Common to its end on the Haldon Hills. Did the Chalk ever extend so far? None can be seen, but in its stead these western heights are covered with a thick sheet of flinty rubble, and every road round Exeter shows great heaps of flints which have been brought from Haldon. Some of them are more or less rounded as if they had been rolled about, either

by the waves upon a coast, or by a river, but many of them are as sharply rough and angular as if they had just fallen from the cliffs of Beer, or the Hooken. Evidently the Chalk, as we see it in these places, once reached wherever the Greensand extended, but in the times which followed it has been removed, and only the hard enduring flints remain. There will be more to be said about these deposits later on.

Flint debris is also known here and there up the Crediton fjord, pebbles of it are found on the Cornish coast, and it is said that angular flints may be dredged from the sea bottom off the Lizard Point.

The whole of the Blackdown Hills are capped by deposits like those on Haldon, and flint pebbles are common in the valley gravels by the Culm, but according to the Rev. W. Downes they are wholly absent from the gravels of the Exe above its junction with its eastern tributary.

If we travel eastwards from Devon we find the Chalk extending, through Dorset and the Isle of Wight, all the way to the coast of Kent; forming the expanse of Salisbury Plain, the long lines of the Berkshire Downs, the North and South Downs on either side of the Weald, and extending northwards by the Chiltern and Gog Magog Hills to the white cliffs of Flamborough Head in the north, and to Norwich in the east.

This is not its limit. There is a kind of chalk in Antrim, where it rests on eroded surfaces of Liassic and Rhaetic beds; and other patches are found in the Isles of Mull and Arran, and elsewhere on the west coast of Scotland. These outlying bits are particularly interesting, as they show that the Chalk once reached at least as far as the distant shore lines of the Liassic Sea. From the intervening districts it has been removed, but in Antrim and Mull bits of it have been preserved under some floods of lava poured out at a later date, while in Arran we ascertain its former presence from a number of great fragments which fell with the underlying Jurassic rocks into an ancient volcano of the same age as the lava flows.

The Chalk sea evidently extended further than the Greensand, and marks a greater submergence, so great in fact that

all the south-eastern part of England was submerged, and the water penetrated far into the western and northern land.

In the south-eastern parts of England it is divided into three sections, Lower, Middle and Upper. The Lower Chalk contains a considerable quantity of marl. Its bottom beds contain glauconite, and are called the Chloritic Marl. These are followed by the Chalk Marl, as it is called, which contains a considerable proportion of muddy material, and this again by a grey chalk, the total thickness shown in the cliffs of Kent being about 200 feet.

Now the whole of this Lower Chalk is rich in fossils, ammonites, sea urchins, and others. Each sub-division has its own particular assemblage, but throughout the greater part certain ammonites are frequently found. Two of these may be named here which belong to the genus *Acanthoceras*, namely, *Mantelli* and *Rothomagense*, and another which rejoices in the name of *Schloenbachia varians*. These beds are therefore known as the zone of these ammonites, and they are covered by another zone in which a belemnite called *Actinocamax plenus* occurs. All these zones are grouped together in Devon into the few feet of the Cenomanian limestone, a fact which shows how slowly it must have formed.

Indeed if we couple this fact with the eroded Greensand surface upon which it lies we cannot avoid the conclusion that while the sea was deep and still over Kent, it was shallower, and disturbed by rapid currents or other movements further west, so that fine mud, whether calcareous or otherwise, could only collect where sheltered in banks of shells which were themselves too heavy to be carried away to the deeper water in the east. The result was that deposits 200 feet thick in the neighbourhood of Folkestone are only 2 feet 6 inches in Pinhay Cliffs, about 14 feet at Beer Head and 24 feet at Hooken Cliff.

It is, however, to be noticed that the chert beds of the Greensand show an entirely opposite change. They become thicker and thicker as we move westward, and it becomes a question whether they do not, at least in part, represent the shallower water deposits contemporaneous with some of the Lower Chalk. We ought, if this were the case, to find at

towards the sea and to the centre of the Cove. It is possible also to walk through a low natural arch drilled through the top of the Greensand and covered by the limestone and its superincumbent hard chalk, and on emerging on the eastern side we find ourselves at the foot of a vertical cliff which gives a most perfect section of the different beds. The chert layers, black and brown in colour, rise up gently, and they, and their related sands, can be studied in detail.

Returning to Beer Cove, and crossing to its western side, we find the same flooring of cherts rising out of the sea and again covered by the same beds in the same order. There is, however, one difference. The Cenomanian limestone does not rest on a *green* sand, but on a brown layer. Moreover, in the corner of the Cove, on each side of a pile of fallen blocks of nodular chalk, the Greensand forms the base of the cliff, and it is seen to be either false bedded on rather a large scale, or else the Cenomanian limestone lies on an eroded surface. There is one place where the limestone projects a foot or so beyond the crumbling surface of the sand, and its under side can be seen to be full of fossils. Indeed it is evidently mainly composed of the shells of ammonites and other organisms, mixed up with calcareous mud, and grains of quartz sand; while it rests upon what look like the eroded edges of layers of ruddy brown sand, with numbers of green glauconite grains throughout their mass.

All along the line of cliffs which run out towards Beer Head we can trace the same divisions. There is a shelf of waveworn Greensand projecting from the base of the cliff, and above it lie the limestone, flintless chalk, and white chalk, in their proper order, and the same lines of flints can be followed winding as parallel markings from point to point.

On the western side of Beer Head the same divisions are to be traced, but if measurements are taken of the thickness of each they will be found to differ considerably from those taken at the White Cliff. But more important changes soon become evident. The great cliff under the Coastguard station on Beer Common gives another fine section. It is known as Hooken Cliff, while the slipped portion which broke away from the main mass in the year 1789 is called Under Hooken.

Beer Cove: Cenomanian Limestone on Greensand.

Beer Cove: Cenomanian Limestone on eroded Greensand.

Sussex the flints do not come in until the next zone is reached.

The top of the Middle Chalk consists of the zone of *Holaster planus*, a particular species of sea-urchin which makes its appearance in some abundance. This zone is about 60 feet thick at Beer, and extends from the top of the main cliff, along the eastern part of the cove to a line about half-way up Annis' Knob. In Sussex this zone is only 48 feet thick.

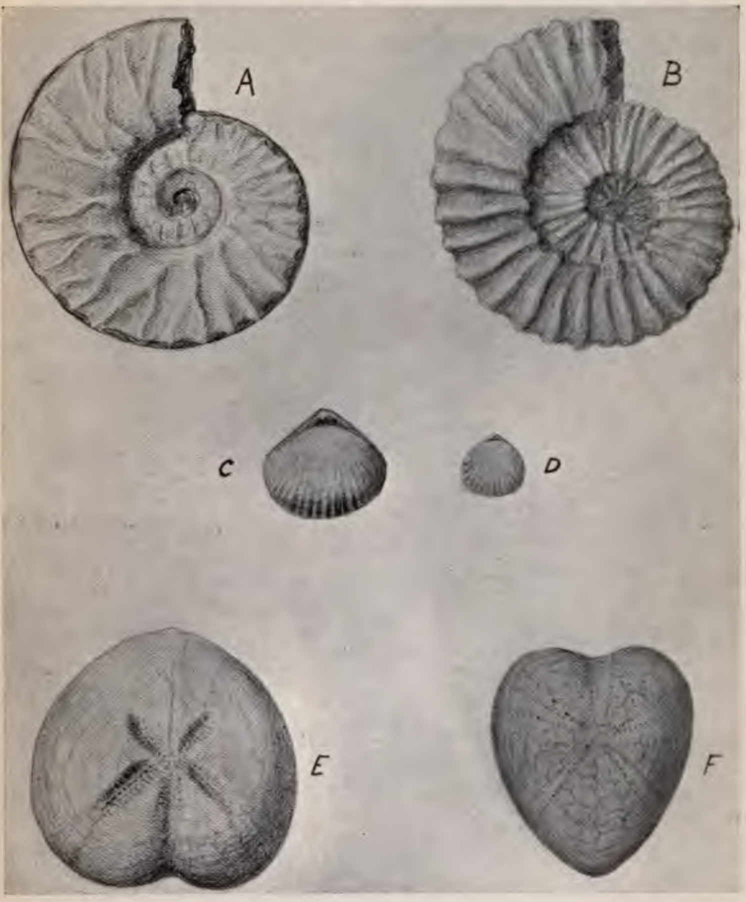
The upper part of Annis' Knob shows a part of the zone of another sea urchin called *Micraster cor-testudinarium*, and is the local equivalent of a zone which measures over 100 feet in Sussex. The same zone forms about 50 feet of the top of the Pinhay Chalk Cliffs, and these are the only representatives in Devon of the whole of the Upper Chalk.

Now the Sussex cliffs show a thickness of nearly 550 feet of chalk higher up than the top of Pinhay Cliff; and an interesting problem at once presents itself.

We can see that all over Devonshire, wherever there is Chalk or Greeensand, these deposits are covered with flint gravels and rubble, much like that which has been described as lying on the Greensand of Haldon. It has also been pointed out that these rubble deposits consist partly of sharp angular flints which cannot have been brought from a distance, but which must have been simply dropped into position by the removal of the Chalk.

Similar removal is even now going on all over the Chalk districts. Rain water percolates through the soil and dissolves some of the products of vegetable decomposition, such as carbonic acid and humic acid. When it comes into contact with the Chalk, it dissolves a little and then filters away. The soil thus steadily descends, slowly and irregularly. But the insoluble flints remain.

Now is it possible that a sheet of Chalk more than 500 feet in thickness once extended over Devon, and that the whole of this has been removed except its flints? We have no means by which we can answer this with absolute certainty, but we have one clue which throws at least some light upon it. The fossils of the Chalk are not restricted to its calcareous portions.



Zone Fossils from Beer and Seaton.

A.	Schloenbachia Varians	⅔ natural size.
B.	Acanthoceras Mantelli	⅔ ,, ,,
C.	Rhynconella Cuvieri	1½ ,, ,,
D.	Terebratulina Lata	1½ ,, ,,
E.	Micraster Cor-testudinarium .	⅔ ,, ,,
F.	Holaster Planus	⅔ ,, ,,

The flints are often formed around some organism such as a sea-urchin, a shell, or a sponge, and in such a case the fossil consists, not of carbonate of lime, but of flint, as hard and enduring as its matrix.

The Haldon flints contain numbers of such relics. The stone breakers know them well as cockles, gipsies' crowns, and such fancy names, and a little use of the silver hammer will easily secure them.

The missing zones, in ascending order, are the zone of *Micraster cor-anguinum*, an urchin much like *cor-testudinarium* the zone of *Marsupites testudinarius*, a creature something like the feather stars of to-day; and finally the zone of *Actinocamax quadratus* a particular species of the family of Belemnites, which were not very different from our modern squids and cuttle fishes. Of these zone fossils the *Micraster* is abundant in the flints, and a few plates of the *Marsupites* have been found. The Exeter Museum has several specimens from Haldon and another was found by Mr. F. G. Collins on Beer Common.

It is evident, therefore that these two zones did once extend over Devon, but there does not appear to be any record of the Belemnite, or any of the fossils associated with it in the Norwich Chalk, which is the highest known in England. This is, of course, only negative evidence; but, as the sequel will show, the Chalk period was ended by an upheaval of much the same character as the submergence. It is likely, therefore, that the western districts would first emerge from the waters, and that the upper zones should be either absent, or thin, or represented by shore materials.

This leads us to a consideration of the conditions under which the Chalk was formed.

We have nothing exactly like it now collecting. The nearest resemblance is the Globigerina ooze of the North Atlantic, which dries into a pale grey deposit not unlike the grey chalk, or some of the marly seams which have been mentioned. The Atlantic ooze contains a percentage of silica which is absent from pure Chalk; but that absence is fully accounted for if we suppose that the siliceous matter is concentrated into the flints. The great point of resemblance

is the fact that both are composed very largely of the skeletons and fragments of skeletons of Foraminifera.

The Globigerina ooze is a deep-sea deposit, and it has been generally concluded that the Chalk must have been formed under similar conditions. But the accumulation of Foraminiferal skeletons is not due to depth at all. Indeed the depth is rather a preventative, because it helps the solution and corrosion of the calcareous shells. The essentials for the rapid gathering of such a deposit are a warm surface temperature, so that the tiny organisms can flourish freely, and an absence of land derived material to obscure their remains.

The Lower Chalk contains many signs of contemporaneous erosion, and the Cenomanian deposits of Somerset and Devon are studded not only with well rounded grains of sand, but contain even rounded quartz pebbles. These facts both point to shallows, sandbanks, or even shingle, so near that the pebbles could be rolled along, either by powerful tidal currents or by the disturbance due to waves.

The disappearance of the lower beds at Hooken Cliff is the strongest argument of the kind. Here is a spot which must have been a sandbank while Chalk was forming close by.

Rapid changes in the thickness of the different zones, such as are recorded in Dr. Rowe's paper on the Devon coast, are also quite inconsistent with the idea of a deep sea, but fit in admirably with the notion of a comparatively shallow one, into which scarcely any land derived mud could ever come, and whose floor, every here and there, rose near enough to the surface to be affected by its movements.

When dealing with the chert beds of the Greensand they were explained as pointing to clear water in which siliceous sponges flourished in prodigious abundance, till the sea was paved with a mud formed of their spicules, Into this sea from time to time came an influx of sand. Sometimes the sandy layer was thick enough to wholly hide the sponge deposits. At other times the two became mixed, and material was formed such as we find at Blackdown, where sandy layers occur which contain pockets filled up with a fine yellowish powder which is a tangled mass of spicules easy to see with a pocket lens.

Remove the shores a little further, and perhaps thereby open up a wider access for warm currents from the ocean, and the waters will swarm with calcareous Foraminifera and with the sea creatures which prey upon them, and on each other. Then the deposit forming on the sea bottom will be an impure chalk. Sand grains will wash from the Greensand where it stands high enough and, in the shallows around, the shells of larger organisms will collect, while the smaller Foraminifera will be washed by tides and waves away to greater depths, except where sheltered by the shells. Hence the sandy Cenomanian of Devon and the thicker masses of the Lower Chalk of the south-east.

Still further push back the shore lines, or lessen the distant river slopes, and even the finest mud will only reach the sea floor after times of unusual flood or storm. Then the accumulation of Foraminiferal ooze, mixed with the flinty tests of Radiolaria and the spicules of sponges, will go on uninterrupted, while one after another different species of creatures enter the region from other parts, or are evolved within it, only to be replaced in turn by others.

Now and then, at long intervals, we must suppose the sea floor rose within reach of surface movements, to sink again, each oscillation being accompanied by some geographical change, which would slightly vary the environment, and so tend to make some change in the life of the whole district so affected. Thus it comes about that we find bed after bed of the chalk regularly deposited over a wide district and then we come to some horizon at the junction of two zones where there are symptoms of surface waste.

There is no need whatever to assume great depth, in any part of the Chalk, but on the contrary, every here and there are signs which can only be accounted for by a shallow sea perhaps less than 100 fathoms deep.

If this is so, then in attempting to reconstruct the map of this part of the globe, we do not need to follow the example of the older geologists and regard our district as reduced to a trifling archipelago whose islets were the summits of our mountains. The waters certainly spread over the whole of

the region once covered by the Lias Sea, and overlapped its shores, running far up the valleys and overflowing the low lying districts. Meanwhile if we suppose the Atlantic (as we did in accounting for the chert beds), to have drawn nearer, it is possible that the two seas may even have joined, and strong currents may have ebbed and flowed through the straits.

But the general slope of the district was still from north-west to south-east, and it is not probable that any such connection was formed in the neighbourhood of Devon and Cornwall; and the improbability is heightened by the sequel.

We have no evidence of the Chalk having spread in Devon much further than the Greensand, and all we know of such western relics as the flints already mentioned, would be the natural consequence of a small extension of the old Liassic fjords.

The approach of the Atlantic can be entirely accounted for by a sinking of the country which formerly lay on the western side of the Caledonian Ranges, but the ranges themselves, and above all the district where they joined on to the Hercynian, would be least likely of all to become submerged.

It seems then that South-Western England was most likely part of a rock-shored land which extended from Ireland and Wales to Britanny, and which may or may not have been separated from the Northern Continent which still existed from Iceland and Scotland to Scandinavia, and which still bridged the North Atlantic; a country clothed with forests somewhat resembling those of Southern Europe to-day, through which the descendants of the Jurassic Deinosaurs wandered, while the empire of the air was disputed between the strange toothed birds and long-winged representatives of the vanishing Pterodactyles.

The Secondary, or Mesozoic, Era was hastening to its close, and the strange beasts which characterised it were nearing their end. A new map of the world was coming, a new set of conditions, and higher forms of life.

CHAPTER XII.

The Plateau Gravels.

With the beginning of Tertiary time we reach an important stage in the modelling of the county. The materials of its structure had been almost entirely accumulated; they had been placed in something very much like the relative positions in which we find them now; and the main lines of the county architecture had been determined. The changes which had still to be carried out were some trifling rearrangements of the superficial material, and the final sculpturing of the hills and valleys by the action of rain and rivers, sun and frost.

The Era was ushered in by a widespread upheaval which almost exactly reversed the long subsidence traced in the preceding chapters. So far as the British region is concerned the movement was not, at first, complicated by any considerable flexures of the crust. It was a general uplift which step by step restored an eastward sloping country, stretching from the high lands of the west to the sea shores in the south-east.

During the long submergence the parts of the old Jurassic land which were overflowed must have been buried under a deep mantle of new deposits—Greensands and Chalk—a mantle thin and unimportant in the extreme west, and growing thicker and thicker towards the east.

Now it has been pointed out that the burial of a land surface beneath such a cloak of new sediment does not necessarily obliterate its features. The contours of the old land tend to persist. Their asperities will be rounded off, and the amount of such softening will be roughly proportional to the thickness of sediment. Hence, in the east it is probable that if we could compare the buried land of Wealden days and the newly emerged surface of Tertiary time the contours of the latter would show little of the former, except a few shallow hollows above what had been the principal valleys, and a few gentle swellings above the main lines of hills.

On moving westward, where the Cretaceous mantle becomes thinner, the new surface will approximate more and more to the old; becoming a smoothed and softened copy of the buried surface when we reach the neighbourhood of the Cretaceous shore.

Those parts of the continent which had not been submerged will, of course, show the same features as of old, modified only by further erosion due to surface agencies.

When, then, the upheaval began, the streams falling from the heights will have found their ancient channels still marked out for them on the upraised sea floor, and, as the shore retreated eastwards, step by step the old map will have been re-established. In the west even the minor streams would be thus resuscitated. Further east, as in Dorset, only the major features would emerge, and still further east only the largest and boldest.

It is important to realize this fact clearly, for it will need to be remembered further on.

In the process of emergence, as the shore retreated eastwards the waves would beat on the rising land, strewing its surface with sand and shingle, and, if no other agents had been at work the new country would have been left with a stratum of littoral deposits covering the whole, from the western limit of the Chalk sea to the most eastern end of its retreat. But other agents must at once have come into operation. Rain, rivers, and all those many agencies which are grouped under the general head of subaerial denudation, would come into play. The sands and shingles of the shore would be re-arranged as gravels and river sands, and ground down into fine mud; while in flood time fine clayey detritus would be borne from the western heights, to settle in any hollows, and to be spread over the floor of the shrinking sea, mixed with river-rolled pebbles and with the wave-worn detritus of the beach.

Such should be the geological record of the time. Let us see what it is.

If we climb to the top of any of the great hills which command wide views of Eastern Devon, such as Haldon, Cadbury, Hembury Fort, or even the ancient battlefield

between Pinhoe and Poltimore, we cannot help noticing how all the eastern heights reach up to about the same altitude and are capped by a fairly level plain. The idea is at once suggested that the whole country was once at that height, forming a gently undulating surface into which the modern rivers have dug their way. The view from Peak Hill looking inland, or that from the hills south of Honiton looking northward, is so striking that no one can help feeling that the modern scenery has been chiselled out of an ancient plain.

This conviction grows stronger with further investigation. All round the Blackdown Hills similar valleys exist, trenching the sides of a flat tableland. If we move into Dorsetshire by Lyme Regis and Hardown we find the same features again and again, and can thus trace the fragments of a plateau from Haldon all the way to the heaths and moors which stretch round Studland and Poole Harbour.

American geologists have invented an expressive term for such a common level attributable to some definite epoch. In England it used to be called a plain of denudation, but in the States they call it a *peneplain*, which expresses no idea except that it is almost flat.

We find, then, that the Cretaceous rocks of Devon and Dorset rest on the eroded surface of the old Jurassic land, which may be called the Jurassic peneplain, and that they are capped by another surface of erosion which might be called the Post-Cretaceous peneplain. The first was made by the advance of the sea modifying a land surface, the second by the retreat of the sea and the advance of land conditions over a sea bottom.

The Tertiary Era is subdivided into a number of periods, which in order of time are known as Eocene, Oligocene, Miocene and Pliocene, terms which refer to the proportion of existing shells which are found in their respective deposits. Thus Eocene means the "dawn of the recent," and beds of this age contain a great assemblage of shells of which, according to Geikie, about three and a half per cent. are those of still existing species.

If, now, we are right in believing that the Post-Cretaceous peneplain, which forms almost the dominant feature of the scenery of East Devon, was formed during the retreat of the sea, this must have been in Eocene times. We should have expected therefore to find some of the materials left behind by the retreating waves dated beyond question by their fossil contents. Unfortunately this is not the case. The beds which cap the hills contain nothing organic, except fossils which have been clearly derived from the underlying Greensand or Chalk. Their place in Tertiary time has only been established in recent years by Mr. Clement Reid* by working westwards from more eastern deposits whose date is much more clearly shown.

There are two districts in the east where Eocene beds are well developed. One is the south of Hampshire and northern half of the Isle of Wight. The other is the district around London. The beds of these two areas may be tabulated thus—

	Hampshire	London
Upper	Barton Sands Barton Clay	Upper Bagshot Sands
Middle	Bracklesham beds and Leafbeds of Alum Bay, &c.	Middle and Lower Bagshot Sands
Lower	London Clay Woolwich & Reading beds	Lower Bagshot Sands London Clay Blackheath beds Woolwich & Reading beds. Thanet Sands

The Thanet Sands seem only to have formed in the London basin. They contain about 70 species of marine shells and a few plants.

The Woolwich and Reading beds consist of irregular patches of clay, loam, sand, and gravel, well water-worn and sometimes containing marine shells. But, as we work westward, the fossils disappear, the gravels become

* *Quart. Jour. Geol. Soc.*, 1896, p. 490; 1898, p. 234.

subangular or much less worn, and fragments of Greensand chert and sponge spicules appear.

The London Clay also, which is highly fossiliferous near Bognor, becomes more sandy towards its western limits and loses its organic contents.

The Bagshot Sands point still more strongly towards a western origin. At the eastern end of the Isle of Wight they are 150 feet thick, but expand to 600 feet at the western end, where they contain lenticular patches of white pipe clay, with plant remains.

In the cliffs of Bournemouth the same sands and pipe clays occur, but coarser grains are more abundant, fragments of Greensand chert and splinters of flint occur, and more significant still, there are fragments of black radiolarian chert.

Beyond Wareham, in the interior of Dorset, the sands are much coarser and become gravelly; unworn flints and little worn chert become abundant, together with pebbles of vein quartz, hard quartzites and other western materials. Pipe clay is abundant, and while the radiolarian chert, black grit pebbles, and white quartz pebbles all indicate an origin in the Culm and Devonian rocks, the pipe clay is exactly like that which is found everywhere around the fringe of Dartmoor.

From the moorland and heaths of Dorset the gravels stretch westward on top of the Chalk, and then on to the flint rubble. The railway cuttings on the Lyme Regis branch show some excellent examples. In one cutting there is nothing to be seen except angular flints mixed up with rounded and subangular pebbles of flint, chert, and other western rocks, in a matrix of sand and pipe clay most irregularly mixed.

In another exposure layers of sand are interspersed among the other substances in such a manner as to suggest rearranged Greensand.

The flat-topped hills of Blackdown, Honiton, and Haldon show similar gravels resting on, and to some extent mixed up with, the rubble of unworn flints which we have already attributed to the solution of the Chalk. On Haldon,

just north of the road from Exeter to Chudleigh, these deposits are extensively worked for road metal. There the Greensand is covered by the unworn flints, among and above which lie the worn pebbles and layers and pockets of sand and pipe clay.

There can be no doubt, then, that these plateau gravels, as they are sometimes called, are of Eocene age, or that the finer and more water-worn gravels of Dorset are the representatives of the coarser and more angular beds of the Exeter district. But we want to know much more about them than a rather vague determination of geological date. Do the whole of these gravels coincide in age with the Bagshot Sands, or are parts of them coæval with the London clay or still earlier deposits?

Again, by what agencies were they produced?

Mr. Clement Reid answers these questions by regarding them as the gravels spread over the wide valley of a large river which flowed eastwards. But they differ in many ways from ordinary river gravels, and they spread over so wide a district that if they were wholly due to a stream it must have been very large and very rapid. A river capable of carrying the unworn or slightly rounded fragments would have been far more likely to have scooped out a narrow steep-sided valley; and one which could build up a plain of such width would almost certainly have built it with a much larger proportion of fine material mixed with a smaller part of well rounded gravel. In Dorset, Mr. Reid has pointed out that the London Clay, which is undoubtedly marine, seems to have been eroded, so that the gravelly Bagshot Sands lie on the eroded surface and overlap it, resting then directly on the Chalk. In the same district there are pebbles of Purbeck stone* which prove that at the time the gravels were formed, not only Greensand, but even some of the underlying Purbeck beds must have been exposed. Even in Devon fragments of Greensand chert appear with the flints, so that we must suppose it was uncovered, and from their abundance the area exposed must have been considerable.

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*op. cit.

In a previous chapter it has been shown that in all probability the coast line of the Chalk sea was not much farther westward than that of Greensand times, and that neither of them were more than a few miles west of the present limits of the formations. How comes it, then, that the gravels lying immediately upon the remnants of Chalk should be full of fragments of a rock which lies properly beneath the Chalk?

It is possible that the western Greensand fjords were never filled with true Chalk, but that in the narrow waters close to shore the deposits coæval with the Chalk of the more open sea were identical with Greensand. But even if this were not the case, it is tolerably certain that the shore deposits of Chalk were thin and sandy, such as would be easily removed by the waves of the retreating sea, or by the streams, which would necessarily return to their old valleys as soon as those were raised above sea level.

The only interpretation which seems to meet all the difficulties is the one which has been foreshadowed, namely that these gravels and sands are primarily marine, created in the first instance as shore and shallow water deposits due to the retreating sea, and that they have been rearranged, sorted and distributed eastwards by the various streams. The steps by which this was done would not be restricted to any narrow limits of time. They would begin directly a part of the sea floor came near enough to the surface to undergo erosion. The fine unconsolidated mud would soon be washed away into deeper water, and as this would be mixed with land-derived muds, the resulting deposits would be quite different from Chalk. Flinty nodules would be left on the surface to be thrown up on the beach, and more or less rounded like the flints on a modern shore.

Meanwhile the streams which were reoccupying their temporarily submerged valleys would soon cut down through the remaining Chalk and lay bare the Greensand and its cherts, pebbles and fragments of which would be washed shorewards, to be there mixed with the wave-formed material.

Suppose that at this period the beach line lay along the Haldon ridge. The deposit would rest upon a stratum of Chalk covering the underlying Greensand and would be arranged much like a modern beach.

But as the upheaval progressed, the beach line would retreat eastwards, and as it did so the older deposits on Haldon would in turn become subject to other actions. Soil would form upon them, percolating water charged with humus would begin its work of corrosion. Streams would flow over them cutting channels through them, re-arranging their components and carrying some to the newer shore.

Meanwhile the fine mud, whether originating on the western heights, or on the beach strewn slopes, would be carried off in flood time to the distant sea, where it would settle down as a deposit of clay.

So the process would go on, the minor streams carrying their materials into the larger ones, trundling the stones along and carrying the finer fragments in suspension. But unless these minor streams flowed down much steeper slopes, their carrying power would be far less than that of the main rivers, and the slopes of the plateau on which we find most of these gravels now can never have been very much greater than they are to-day. It is to the larger rivers then that we must look as the chief agents in the bodily transfer of pebbles any considerable distance towards the east, though their tributaries would be amply competent to effect substantial changes locally.

The result would be that in any given place the materials of the deposit would consist chiefly of local rocks, and that as the shore retreated eastwards the pebbles of western origin would get gradually smaller and more rounded, and that the accumulations beneath the sea would be finer still: clay in the deeper parts, sands and fine gravels nearer shore.

While the coarse shingle was being thus spread over Devonshire, finer gravels and sand must have formed in Dorset and probably clay still further east. When at last the shore reached Dorset the waves and streams would

have to remove the new accumulations before they could attack the underlying Chalk. If the progress of the upheaval was rapid, this would only be partially effected, and we should find finer western gravels or sands intermixed with coarser locally formed stones. But if there should be, as indeed would almost certainly be the case, any considerable pause in the shift of the shore line, the gravels or sands or clay would be eroded, and locally formed beach deposits would be built up from their remains and those of the underlying local rocks. It seems that the erosion of the London Clay beneath the gravels and sands of Dorset can be easily explained as due to a pause of such a nature.

The seams and pockets of pipe clay would be a natural consequence of the eastward slope of the land. The rivers which were capable of rolling pebbles from Devonshire would be a still more efficient means for the carriage of the finer mud from the great granite masses of the west. Some of the white clay bands in the Chalk may well have come from the same source, and if, in the process of erosion, these clayey bands were exposed, the solution of their chalk would leave a pipe clay indistinguishable from that which comes direct from granite.

So far we have made no reference to three other important features presented by these deposits, the abundance of unworn chips of chert and flint, the absence of fossils, and the exceedingly confused arrangement of the materials.

Now the pipe clays of Alum Bay, in the Isle of Wight, and those of Bournemouth have yielded a large number of leaves of plants which are of such kinds as to imply a tropical climate. There is no doubt that as the land emerged above the sea it became quickly clothed with a dense forest — a forest resembling that of the Malay Peninsula of the present day. The great carrying power of the streams also implies a humid climate, and indicates heavy and frequent floods.

Under such circumstances trees and bushes are torn from the banks of rivers and carried far down stream,

dropping the subsoil and splintered surface rock entangled in their roots as these are washed and torn.

A dense covering of vegetation also gives rise to a deep surface soil rich in humus. Rain falling on such a soil becomes highly charged with acid bodies, which corrode many rocks, and have a special power of dissolving chalk. Over most of the districts where these gravels are found they rested on chalk. This must have been dissolved away, solution taking place upon its surface, but acting always most irregularly. In some places deep hollows would be eaten out—hollows into which the overlying gravels, and subsoil, would descend. We have only to visit some large chalk pit, such as are common in a chalk country, to see how even our modern soil sinks down irregularly into the Chalk, forming what are called sand pipes. They may be seen everywhere where the Chalk is laid bare, cliffs, railway cuttings, house foundations, all exhibit the phenomenon, and neither rainfall nor humus is anything like so abundant now as was probably the case during the earlier part of the Tertiary Era.

As the Chalk was thus eroded under the soil, the flints were comparatively little changed. At least they would neither be rounded nor bodily removed. They would therefore remain to be irregularly mixed with the gravel and subsoil as it slowly sank.

Again the clayey particles of the marl bands so abundant in the Chalk would not be removed. They would remain as streaks and lumps of white pipe clay.

It is possible to form a rough, but approximate, estimate of the thickness of chalk which has thus disappeared. We have pointed out that many of the Chalk fossils are composed of flint, and are really part of the flints, and that these fossils are largely extracted from the Haldon flints when broken up for mending the roads. We thus find that the flints of Haldon represent all the zones of the Chalk which are found at Beer, and one higher zone at least. If, therefore, we estimate the thickness of chalk which has been dissolved away from Haldon underneath the originally marine gravels, at one or two hundred feet,

we are almost certainly far within the mark. But the irregular removal of only one hundred feet of rock from under a layer of gravel, letting down a bit here and a bit there, would inevitably leave the whole mixed in the greatest confusion with the insoluble residues.

The structure of the deposit is therefore easily explained, and the absence of fossils, except those derived from the older rocks, would be a consequence of the same causes. The solvents which have removed the Chalk would also remove any calcareous shells, and no hollow casts of them could possibly survive the confused and irregular movements accompanying the descent of the deposit as the chalk was dissolved.

It may be objected that the very causes to which we have attributed the transfer of material to the east would surely have long since removed the whole of any such littoral deposits as we have supposed. The answer is that they have been thus removed wherever the carrying power of the streams has been sufficient. If we examine a map, such as the new sheets issued by the Geological Survey for Exeter, Teignmouth and Lyme Regis, we see the Eocene deposits capping the flat-topped hills, but as a general rule entirely removed from the lower ground. A glance is enough to show that the portion which remains is far less than that which has gone.

Where would the removal take place most quickly? And where would it be slowest?

In the first place the deposits, even before any considerable removal of the Chalk, must have been eminently porous, so that the greater part of the rainfall must have soaked straight in, to percolate underground until it emerged as springs along the sides of the valleys occupied by the streams. These streams must have originally marked out certain courses over the rising land, and it does not matter whether these courses were determined (as we have said they probably were) by the contours of the older land. However they were determined they would be quickly deepened, and the rate at which each valley would be enlarged would depend upon the steepness of its slope, and

the volume of water flowing down. On the flat grounds between would be the places where erosion would be at a minimum, since the slope is little or none, and with so porous a subsoil the quantity of water flowing over the surface would be also nil. The only way, then, in which we can satisfactorily account for the survival of the plateau gravels is to suppose that they emerged from the sea with only a gentle eastern slope, that the early rivers flowed in courses somewhere above the modern valleys, and that, in point of fact, the Eocene emergence was the time at which our present system of hills and valleys was initiated.

We use the word initiated advisedly, for it must not be supposed that there have been no changes since. The sequel will show that changes have been numerous and important, and there are instances in which the modern streams most likely flow in the opposite direction to that in which they went in Eocene days.

The early Tertiary Era was a time in which stupendous changes took place in other parts of the world. Among them was the upheaval of the Alps and Himalayas, just as the British chains had arisen in earlier times, and although the main lines of disturbance had now shifted far from our neighbourhood, the terrestrial swell from those convulsions gave the finishing touches to English geography.

The Eocene emergence however witnessed the general marking out of hill and vale over a large part of southern England, and so far as Devonshire is concerned this must certainly have been the case. If we could slip in a hundred feet or so of chalk under our plateau gravels we should restore something like our Eocene hills, and to complete the restoration we must imagine the valleys very much shallower and narrower. Moreover the English Channel had no existence, rivers must as a whole have drained eastward, and those eastward flowing streams would be flanked by tributaries flowing from Exmoor on the one hand, and on the other from Dartmoor and the southern ridges which still bridged the channel southwards, and linked the hills of Cornwall and Devon with those of Normandy and Brittany.

CAAPTER XIII.

The Bovey Lake.

South-west of the Haldon Hills, occupying the surface of a broad basin surrounded by heights, there is a peculiar district which stretches from within a mile of Lustleigh to Kingskerswell, and from Blackpool almost to Ideford. It thus measures some ten miles in length by four miles in breadth. About a mile below Chudleigh Bridge the Teign enters this tract about a mile and a half above its junction with the Bovey, which flows in from the north-west. The district is low lying as a whole, but its margins climb a long way up the slopes of the surrounding hills. The Bovey at Bovey Tracey is less than 90 feet above sea level and the Teign at Chudleigh Knighton is less than eighty. The deposits which characterise the district are at Heathfield only about 100 feet above the sea, but at Blackpool they touch the 300 foot contour line, near Lustleigh they reach 445 feet, near Ideford 400 feet, while on Milber Down they climb up to the 500 foot line.

The peculiar character of this part of Devon is not only shown by its distinct type of vegetation, its industries are also unique. Great open clay pits are dotted over its surface, and the tall chimneys of several flourishing potteries stand up above the pines; clay of excellent quality is raised in very large quantities, and the result has been the opening of a number of sections of the greatest interest.

On visiting one of these pits, the first thing that strikes the eye is the fact that the deposits are somewhat irregularly stratified, and are of all shades of brown and cream colour, while some are white and others actually black. Some of the beds are mere lines of colour on the section, some of them are several feet in thickness.

It has long been known that the brown and black colouring matter is of vegetable origin, and many of the beds are good lignite which can be used as fuel. Indeed in former days it was mined at Bovey under the name of Bovey Coal, and was used in the local cottages as well

as the Bovey Potteries. But the combustible matter always contains enough iron pyrites to produce an unpleasant sulphurous smell, so that it is seldom used for domestic purposes, and the heating power of a ton of lignite is so much less than that of a ton of coal that its use has been discontinued in the potteries. It is, however, still in use for driving the engines used for hauling purposes in some of the pits.

The whole deposit lies in a hollow of the older rocks. North of Newton Abbot this basin has been eroded in Culm and Devonian strata, and south of the town its base is partly Devonian, but chiefly Permian breccia.

There does not seem to be any place where the actual depth of the hollow has been proved, but at the Bovey potteries Mr. Pengelly showed, in his classic memoir on the Lignite Formation of Bovey Tracey,* that the peculiar beds extended to a depth of 215 feet below the present level of the sea. More recently a boring put down by Messrs. Candy & Co., at the Great Western Potteries, close to Heathfield Station, passed through 520 feet of sands, clays and lignites, without reaching their base. As the ground is here less than 100 feet above sea level, the basin must now descend fully 400 feet below the sea, and its depth may really be much greater.

There are three great open pits. The great so-called "coal" pit at the Bovey Potteries was the scene of the careful labours of Pengelly and Heer,† but the bottom is all covered with a sheet of water and the sides of the pit are crumbling away, so that very little of the actual bedding or of the seams of lignite can now be seen. A mile and a half south-east comes the more modern excavation of the Heathfield Pottery. Here it is easy to see how the surface layer consists of gravel, known locally as "head," which rests on an eroded surface of the underlying sands, clays and lignites. But the lignites are here only represented by thin seams, and are not easily recognised. In the Bovey pit Pengelly described 72 distinct beds in a thickness

* *Phil. Trans.*, 1862. † *Op cit.*

Bovey Clays and Lignites: The Plantation Pit.

Heathfield Clay Pit.

of 125 feet exposed, and of these the first consisted of 7 feet 6 inches of gravelly "head."

This surface coating will be referred to later on. It is quite different in character from the underlying series, and belongs to a much later period.

The Bovey beds in the section consist of an upper series of alternating sands, clays and lignites, then 11 feet of quartzose coarse sand and 9 feet of clay, and below this a second series of 23 beds of clay and 22 lignites. It it a noticeable fact that the lignites of each series become thicker as they are lower. Thus the bottom bed of the upper series was about 6 feet thick, the lowest reached in the second series measured 4 feet.

Thoughout the whole of these sections the dip of the beds was fairly regular, and to the south-east, but it is probable that this is only a local feature. At Woolborough a seam of lignite some feet thick has been observed dipping north-east, and other directions have been observed elsewhere.

The best section now open is a very fine one in a large pit east of the road from Chudleigh to Kingsteignton, about half a mile north of the milestone which marks three miles to Chudleigh. To see the section to the best advantage the cart track should be followed through the wood right round the margin of the pit, which is on the right, and hidden by a mound of refuse. On reaching the northern end the track suddenly turns eastwards to some huts used as offices. Here is a fine view of the workings, and of the sections shown on the terraced end of the pit, where clay and lignite are being dug.

It will be at once noticed that the principal beds lie in a basin, rising sharply on each side. The curve of the lower beds is smooth and regular, but an important fact is immediately obvious, namely, that the upper beds show folds and even crumples which are not shown by those they rest upon. It looks almost as if these upper beds had slipped down in the cup formed by the lower, and had puckered themselves in the process. To some extent this may have happened, but some of the disturbances are

still more suggestive of a sinking of the upper beds during the rotting and consolidation of the lower—an action much like that described in the last chapter, but due to the uneven shrinkage of the substratum rather than any removal of its substance by percolating water.*

The base of the section, which can be best seen from the floor of the pit, consists of a thick bed of good clay, over which lies a seam of lignite which is used as fuel in the engine-house to do the hauling throughout the works.

Along the eastern margin of these Bovey beds, every here and there they are seen to be flanked by deposits of coarse sands and gravels, with layers of white clay and coloured sands and containing well rounded Chalk flints and Greensand chert, together with radiolarian chert and other pebbles derived from the older rocks. There is an exposure described by Mr. Clement Reid† not far from Combe Hill Cross.

At Milber Down, Woolborough Church, and, turning westwards along the southern edge of the basin, again at Staple Hill precisely similar beds are shown.

In every case these gravelly strata dip as if they formed the floor of the Bovey deposit, and were continued, at least some distance, beneath the clays and lignites. That they have not hitherto been traced is doubtless due to the fact that all borings which are put down are effected with the object of finding good beds of clay, and would be discontinued on coming into the increasingly sandy beds which form the gradation into the gravels. It is noticeable that these basement beds, if such they are, have not been found along the northern edge of the basin, where the clays apparently end up abruptly on the Culm.

These marginal gravels have been much discussed. They have been thought to belong to the same period as the "head," but there is nothing to connect the two.

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* I am indebted to Messrs. Watts, Blake and Bearn, the proprietors of this pit, for permission to secure the illustration and to examine the workings.

† *Quart. Jour. Geol. Soc.*, 1898, p. 235.

Mr. Clement Reid* has shown pretty conclusively that they are really of the same age as the gravels of the Haldon plateau, that is to say they are Eocene, and therefore belong to the same or an earlier time than the clays and lignites. They may be shore deposits of the same age as the lignites, or they may be what they seem to be, the basement beds of the whole series.

The age of the clays and lignites has also been much discussed. Mr. Pengelly, in 1862,† came to the conclusion that they were of Miocene age. This determination was based upon an investigation by Dr. Heer, of the numerous plant remains and solitary beetle's wing case, which were found during his researches at Bovey. No shells, no bones of animals have ever been found in the Bovey beds—a fact which must be attributed to the water being highly charged with humic acid, which would rapidly dissolve any calcareous shells or bones. But the plant remains, though rarely well preserved, are abundant enough. Ferns of the osmunda kind, oaks, cinnamons, laurels, conifers, figs and palms have been found, and were identified by Dr. Heer as resembling the fossil flora of certain continental beds which belong to a date formerly regarded as Lower Miocene, but now known as Oligocene.

More recently, Mr. Starkie Gardner‡ points out that these same plants, some of which can be positively identified as the same species, are to be found in the white pipe clay seams of the Bournemouth cliffs, which are of undoubted Bagshot age.

It seems then that the whole of these Bovey deposits, except the "head," are of the same general age as the gravels of the plateau of Eastern Devon, and must therefore be a local variation of those deposits whose peculiar characters are due to local circumstances which modified the conditions under which they were formed. What, then, were these local circumstances?

There is a general agreement that the basin was originally a lake. No other hypothesis will account for the fairly

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* Op. cit. † Op. cit. ‡ *Quart. Jour. Geo. Soc.*, 1879, p. 227.

regular stratification of the various beds. Where the gravels lie the incoming streams must have been fairly rapid, and it is not at all unlikely that these gravels really mark the positions where the feeding streams entered the land-locked sheet of water. The coarser sediment would soon settle, the finer, particularly the fine mud which was to make the clays, would be evenly strewn nearly all over the basin. At intervals there must have been long periods during which nothing entered the lake except vegetable matter, and that must have been brought abundantly. Hence the streams must, as a rule, have been too sluggish or too small to have much carrying power. Slowly their carrying power increased. Floods capable of strewing clay, or even sand, over the lake bottom increased in frequency, and the lignites became thinner and less pure. But after an interval the old conditions were re-established and the upper series of lignites and clays laid down.

The Bovey basin, however, lies some hundreds of feet below the top of Haldon, and the bottom of the hollow in the Palaeozoic rocks must be at least 500 feet lower still. How, then, can we account for the fact that Haldon was capped by Greensand, and that by Chalk, while neither of them are to be found among the Bovey beds, though relics of both are abundant in the marginal gravels?

Had the Bovey beds been of Oligocene age it would be easy to suppose that the whole basin was formed after the plateau gravels had been produced. But the identification of both as Eocene puts an entirely different complexion on the matter. The Bovey beds ought to be underlain by Greensand and by flint rubble like that of Haldon. But they are not. There may be some portions of both buried away under the clays of Heathfield, but neither Greensand nor Chalk peeps out on either side.

It has been explained in a previous chapter that the erosion of the rising sea floor would begin nearest the old shore, would be most rapid along the streams and on the steeper slopes, and least of all on elevated flat tracts.

Now the base of the Eocenes on Haldon at present reaches down to the 600 feet contour. If we add on, say

200 feet for the chalk which has been removed by solution, we can then calculate the difference in level between the base of the Eocene on the plateau and the base of the Bovey beds. Put it for the sake of argument at 1500 feet. If now we suppose that when the land began to rise, and the Haldon gravels were the beach line, the general eastward slope was about five degrees steeper than it is now, we bring the two to a common level. Five degrees is only a small angle, and the difference may well have been greater, and the sequel will show that there are good and sufficient reasons for thinking that, as a matter of fact, there was a substantial decrease in the slope at a later date.

If we now bear in mind that all the surrounding heights must have been much loftier, we get at first, steep slopes, and therefore great erosive power, for the streams flowing down from Dartmoor and from the southern hills between Newton Abbot and Ashburton. Moreover, the western land extended far beyond the present limits of Devon, and it is almost certain that the rivers coming into the Bovey region from the west were far more important than the Bovey at the present day. It has been shown by Mr. Jukes-Browne* that the Dart probably did not turn aside from its eastward course, as it now does, but wended its way by Bickington to join the Bovey in the old lake basin. But this is not material to our argument, it would only strengthen the erosive actions and so help their work.

The valleys down which these rivers flowed would be rapidly cleared of all remnants of any beach material left by the retreating sea, and by the time the waves were ebbing and flowing over Haldon, much of the Chalk and possibly also the Greensand, both of which must have spread some distance westwards, would have been cleared away.

This erosion would go on until the bottom of the valley reached down either to the shore level, or to the level of any barrier which existed lower down the stream. The valley drains at present across the ridge of Permian breccias through the gap occupied now by the estuary of the Teign.

***Quart. Jour. Geol. Soc.*, 1904, p. 333.

Probably this was the course then followed, and the valley was eroded to the level of the hard resisting ridge. This was the first stage in the process, and it is a necessary step to account for the removal of the Cretaceous rocks; but it should not be forgotten that we suppose the base of the Bovey valley to be level with the top of the obstructing ridge, which might itself be nearly level with the top of Haldon.

As the upheaval progressed further east it is most likely that the general slope of the country decreased. Indeed, it is believed on excellent grounds that a large part of the Bagshot Sands, and of the sands and gravels of Dorset were formed in shallow shore lagoons rather than the shore of a rapidly deepening sea. Hence we must not suppose that Southern England arose at the same vertical rate from Devon to Hampshire. The records suggest rather that the movement resulted in a greater uplift in the east than in the west, with the result of a distinct and gradual dimunution of eastward slope.

The result would be to raise the hard barrier which lay further down across the Bovey river above the bottom of the Bovey valley, thereby converting it into a lake, and lifting the Haldon gravels above their continuation, a movement which would also lessen the slope of the streams above the lake, reducing their carrying power and so changing their load from sand and gravel to fine clay and lignite.

If this really represents the course of events, the Bovey gravels might be the true contemporaries of the Haldon deposits and really coæval with the London Clay or still earlier Eocene deposits, while the clays and lignites of the old lake were the local representatives of the Bagshot beds of Bournemouth and the Isle of Wight.

It may well be asked why we should attribute the erosion to the Bovey, possibly aided by the Dart, when we have the Teign coming in from the north. The answer is that in those days the Teign followed a different direction, and the north and south portion of its course was occupied

only by a comparatively trifling stream.* This accounts for the absence or insignificance of the marginal gravels on the north, to which attention has been already drawn.

There is no question that the Bovey beds are lacustrine, and there is no other way in which a lake in such a position can be accounted for at such a time. Lakes are formed in other ways than that which we have supposed. They may be formed by a local subsidence. If this had been the case the Cretaceous rocks, or at least the Greensand, should have been preserved, and indeed marine Eocene deposits should have covered and protected them.

Ice action in any form is out of the question, as it is incompatible with the undoubtedly warm climate; and the only other way of accounting for the formation of a lake basin would be to call in an imaginary earthquake or other agent to produce a huge landslip further down the valley whereby the course of the river might be blocked. Of such a catastrophe we have no evidence whatever, and it is indeed most improbable.

On the other hand we have conclusive evidence of a difference in the rate of upheaval not much later on, when the movements in the west were actually converted into a subsidence, and the southern and eastern counties were considerably affected. A beginning of these movements is indicated by an oscillation from estuarine conditions to marine, and by the occurrence of Purbeck pebbles in the gravels of Dorset. This must mean that Greensand and Chalk had been eroded away, and Purbeck beds laid bare, at the time when those gravels were produced, and that time, we already know, was the date at which the Bovey beds were accumulating in Devon. The Purbeck beds could not be eroded without a considerable upheaval, and this was probably the earlier stages of an earth movement which assumed much greater importance later on, and which was accompanied by very important changes in the far west.

If the alteration in the slope was not a continuous change, and it is most unlikely that it should have been unvaried,

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* Jukes-Browne, *Op cit.*

but was brought about by somewhat rapid movements followed by a long pause, and so on, we have an explanation of the division of the lignites into the upper and lower series first recognized by Pengelly.

It must be pointed out that the identification of the Bovey plants as Eocene is not unquestioned. Thus Geikie says,* "one cannot say that the botanical evidence is conclusive, for the species are few and greatly need re-examination;" and again, "In the meantime, however, these various plant-bearing deposits are retained here in the Oligocene series, as possible equivalents of the brown-coal and molasse of the Continent."

If we put the botanical argument entirely aside, and consider only the physical reasoning and deductions based on the mineral compositions of the gravels, it would seem that the first deposit of the rolled gravels of Haldon and the erosion of the lake basin must both have been early Eocene, while the subsequent deposit of the Bovey clays and lignites must represent a later date. Whether this later date was Middle or Upper Eocene, or whether deposition was still taking place in Oligocene time is a matter of little moment.

The Haldon deposits themselves are difficult to date. There is no doubt that Mr. Clement Reid is right in fixing the age of the rounded gravels as Eocene, but those gravels then rested on Chalk. The solution and removal of this substratum must have taken a vast time, and it is more than probable that the Eocene gravels did not attain their present position on the Greensand, or their present confused admixture with unworn flints, until a much later date. In Dorset the underlying Chalk still survives, and remnants of it are to be found at Offwell, Brice Moor, Membury and Salcombe Regis. Its final disappearance from Peak Hill and much of the Blackdown Hills must be regarded as only recently complete.

Text Book of Geology, p. 1251, Ed. IV.

CHAPTER XIV.

The Rivers of Devon.

If we examine a map of Devonshire on which the rivers are clearly shown, we notice in the first place that streams radiate in all directions from Dartmoor, or rather from the western edge of Dartmoor; and that another set arise near the northern coast line and wend their way southwards. We should have expected that the dome of the Moor, to which reference has been repeatedly made, would give rise to a radiating water system, and the Exmoor ridge should similarly be a watershed, and both features should be older than Cretaceous days. But we soon find other things which we should not expect.

The Torridge behaves in a most eccentric manner. The sources of some of its head feeders are only a couple of miles south of Clovelly, and it then flows south-east as if it were making for the strip of red land which ends up at Hatherleigh, but just before reaching that town it turns sharply to the north-east, and then north, and follows a tortuous course to Torrington and Bideford. Its whole course measures about fifty miles, but at Torrington it is only seven miles from a point more than thirty miles higher up the stream. The Taw also presents some anomalies. Rising on Dartmoor, it flows nearly due north past North Tawton. Near Brushford it turns to the east, and then sweeps round at its junction with the Yeo to flow north-west. At South Molton Road Station it meets the Bray, a stream which has flowed almost due south from its source on Exmoor. The Taw pursues its north-western journey, twisting through its deep, wooded valley until it turns sharply to the east on reaching its estuary at Barnstaple. It is noticeable that the valley of the Torridge is continued by the gully up which the railway runs from Braunton to Morthoe and that of the Taw is similarly matched by the course of Bradiford water and the Colom stream to Bittadon.

If the courses of these two rivers and their tributaries are traced on a sheet of paper without any indication of the direction of flow, or of the present coast line, they suggest irresistibly the idea that they are streams rising in the north and flowing south-eastward in the direction of Crediton.

The Barle and the Exe flow south-eastwards until their junction near Dulverton, and then instead of taking the broad hollow followed by the Great Western Railway to Wiveliscombe and Taunton, the river plunges into the gorge which sweeps round through the hard Culm hills as if it meant to go round by Bampton. On meeting the little stream of the Bathern, it turns sharp round to the south and west through the deepest part of its gorge and thence wends its way southwards to Tiverton. Here again is a mystery. Why does it not flow eastwards along the broad valley to Tiverton Junction or Cullompton? Instead, it has cut its way through the harder Culm past Cadeleigh. But its strange behaviour is not ended. On reaching the neighbourhood of Brampford Speke, why does it not turn eastward by way of Rewe, Broadclyst and Clyst Honiton, instead of making an equal turn in the opposite direction to cut its deep valley from Stoke Canon to Cowley Bridge and Exeter?

Similar questions may be asked about the Teign and the Dart, and we have already referred to the probability that both these streams have been deflected from their ancient courses.

Still another problem is presented by the vast size of some of the valleys now occupied by insignificant streams, while much larger rivers flow through comparatively trifling hollows. Either they cannot belong to the same date, or the relative powers of the streams have changed.

It has been pointed out that as the floor of the Cretaceous sea rose and became the early Eocene land, the streams still flowing over the unsubmerged part of the ancient continent would tend on the whole to resume possession of their former channels. This they would necessarily do, unless those old valleys were entirely

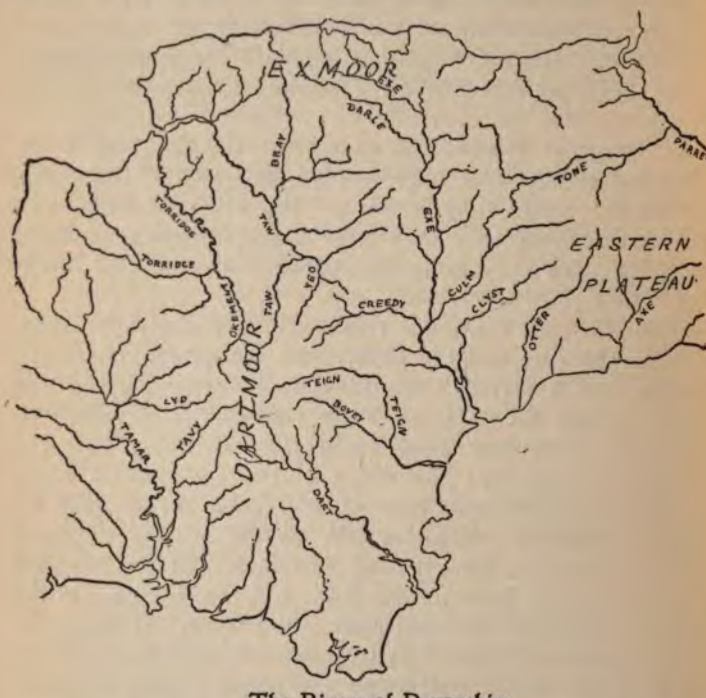
obliterated, or the general slope of the emerging country was different from what it had been before submersion.

In the Devonshire area it has been shown that in all probability neither event would have taken place. The main valleys would still be hollows, and the slope of the country would be towards the east. North of the Exmoor ridge, which must have extended beyond Lundy, lay a broad valley occupied most likely by a large river which flowed eastward south of the Mendips on its way to the eastern sea. In the English Channel, some distance south of the Start, another great river followed a somewhat parallel course.

Throughout Devonshire, except for the dome of Dartmoor, the rivers must have wended their way, on the whole, eastwards; either to join one or the other of these two great streams, or they may have gathered together to form a third which ultimately debouched not far from Dorchester.

Consider now the small rivers which drain the eastern plateau, the Axe and the Otter. At the present time the plateau has a certain slope towards the channel, but the rivers do not follow this. They run obliquely across it. Moreover there are good reasons for believing that the southward slope was the result of the considerable earth movements which came later on and gave the channel its present westward inclination. When the plateau emerged therefore, it must have sloped eastward, and the streams crossing it must have flowed down hill, which means in the opposite direction to that they follow now. If either of these streams is followed to its source it will be found to end in a dry valley, well below the plateau level, which is continued through the dividing ridge into the valley of another stream flowing the opposite way. There cannot be much question that this represents what in Eocene and following times was the actual course pursued. The Otter may thus be regarded as a former tributary of the Tone or of a magnified Parret flowing towards the south-east, while the Axe may have flowed direct into the head waters of the Dorset Frome.

The Taw and the Torridge present a more difficult case. If we examine the course of the Torridge where the Okement joins it at its south-eastern bend, we find the Okement comes in from the south-east. Let us go a short way up this stream. About half a mile before reaching Monk Okehampton a broad valley, now occupied by a little brook, comes in from the east. If this valley be followed it leads



The Rivers of Devonshire.

us to a low gap in the divide near Winkleigh, which is only about a couple of hundred feet above the present level of the Torridge where we left it. The gap leads to the source of a tiny tributary of the Taw, which it joins about two miles above the junction of the latter with the Yeo. In the angle between the Taw and the Yeo there are several channels cutting through the hills. Through any of these

the river may easily have found its way and may then have continued its south-eastward journey, first up the Yeo, then by Morchard Road Station almost along the line now followed by the South Western Railway into the head waters of the Creedy.

Now it must not be understood that there is any absolute proof that the course traced out was in point of fact the

Probable River System in Early Tertiary Times.

actual track of the Eocene and Post-Eocene river. There are two or three other routes by which the connecting links may have passed, but the one described fits best with what we know of the previous structure of the country and follows the line where most erosion was effected before the drainage system was changed. We can be certain that if it were possible to fill in all these channels to a depth

proportionate to the erosion which the present rivers can perform, and were then to restore the general eastward slope of the whole county, such would be the direction of flow. The estuary of the Taw, of course, would not exist, and the two portions of the Torridge, the Taw and its tributaries, would only be the upper feeders of the Creedy, and they would present a map of a perfectly normal river such as we should have expected to find at the date we are considering. A comparison of the two maps shows the difference.

The greater Creedy thus supplied would flow down its present valley to St. Cyres, but where it most likely went next is again a difficult problem. Bearing in mind what we have said as to the general eastward slope and the certainty that the high plateau was continued far over the present English Channel, it seems unlikely that it turned southwards. Neither can it well have flowed over the plateau. We should look for its ancient valley where the removal of material has been greatest, that is to say along the north-eastern face of the Blackdown Hills.

Along the valleys of the Culm and Tone an amount of erosion has been effected which seems far too great for the existing streams and out of all proportion to their size. Not only have miles and miles of Eocene and Cretaceous rocks been cleared away, but the Permian sands and even the Budleigh pebble bed have been deeply trenched.

Along this track then it seems most likely that the drainage of northern Devon went, flowing along the course of the Tone to join the river of the Bristol Channel and turn with it south-eastward past Yeovil and Yetminster, also to join the Frome.

Again we find we can thus construct a normal river map such as would be likely to be marked out on a new land. The principal channels would lie approximately where we have other reasons for thinking they would be, and we supply the great carrying power which can alone account for the distant travel to the Dorset estuary of the heavy debris of northern Devon.

The Exe and Barle would most likely turn off before reaching Tiverton to join the main stream near Sampford

Peverell, and the Cadeleigh Dart, sweeping round by Silverton, would be another tributary from the north. The estuary of the Exe and the Clyst would be marked out by two southern tributaries, and it is probable that the overflow of the Bovey lake curved northwards and formed the continuation of either the Otter or the Axe.

Mr. Jukes-Browne has given reasons* for believing that the Teign continued its course from Clifford Bridge across the ridge near Holcombe Burnell into the valley of the Alphin brook and so joined the Exe. It seems, however, at least equally likely that it diverged from its present track near Dunsford Bridge and following a more northerly direction entered the present valley of the Exe at Exeter or Cowley Bridge, and then swept on by Stoke Canon to the great river of North Devon. If so it would have been the Teign which first began what is now a part of the valley of the Exe. Truly a strange result, but one which is far from improbable.

It may be asked why we suppose always that the rivers must have followed existing valleys. The reason is that a valley once formed tends to remain a valley, and can only be obliterated by means which do not seem to have been brought into operation in Devon since the Cretaceous submergence. The streams which excavated them may be diverted, the direction of their slope may be reversed, but unless some agent is set to work capable of levelling the hills, or of filling the valleys with material as hard and resistant as the hills, they will necessarily remain as a record of the past.

The exact course these streams followed can only be traced, if traced at all, by a laborious research on the valley gravels more recent than those of the plateau. This has not yet been done, so that the course traced in the foregoing pages must be regarded as a hypothesis backed up at present only by general arguments, and as the alternative which seems to be least at variance with the facts at present known. It will be remembered that in

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* *Quart. Jour. Geol. Soc.*, 1904, p. 319, *et seq.*

order to account for the erosion of the Bovey basin so as to form a lake, we found it necessary to assume an eastward slope, perhaps five degrees or more steeper than at present. It is significant that if a similar tilt were given to the whole of North and Eastern Devon, together with a northern inclination of the southern portion, many of the changes we have imagined would be actual facts, even without any filling in of the channels such as we supposed when dealing with the Taw and Torridge.

Such, then, is a probable restoration of the county itself. But through Eocene and Oligocene times into the Miocene age it was far from any shore, being part of the high ground of a continent which included almost the whole of the British Isles and Western France, and which was linked to Greenland and America by way of Iceland. The climate through all that long time was tropical, and all sorts of strange warm-blooded animals roamed the luxuriant forests and sheltered in the caves. In Eocene times these animals bore little resemblance to those of to-day, but as the centuries rolled by the likeness became stronger and stronger, until in Miocene days we find elephants, rhinoceros, anteaters, hogs, otters, antelopes, great tigers, and even manlike apes.

The early Tertiary periods witnessed some of the most important geographical changes which the world had seen. The great chain of mountains which dominates Europe and Asia received its principal uplift. In Eocene time a broad deep sea had extended through Europe and Asia to the Pacific, a sea which swarmed with Foraminifera in such abundance that their remains have built up massive limestones, called the Nummulite limestone, which is sometimes thousands of feet thick. Upheaval of this tract began in the Oligocene period, leaving a strip of sea extending through the heart of Europe to the Black Sea and the Caspian. A further and greater movement, of Miocene date, raised the young ranges higher still, leaving the Black Sea and Caspian as remnants of the Eocene Mediterranean, while the Nummulite limestone rose up to heights of 10,000 feet in the Alps and 16,000 feet in the Himalayas.

Movements on such a scale have far reaching consequences. The old arrangements of land and water were finally destroyed, and the modern distribution was begun. Volcanoes broke out in new directions, one line being marked by outbursts in the Auvergne, the Eifel and eastwards on the northern side of the rising chain, while a still more northern group made its appearance, either in Eocene or Oligocene time, on what had been the floor of the northern end of the Lias sea. Over large districts in northern England and Ireland and along the western coast of Scotland, innumerable fissures were formed, up which the molten material rose, to be poured out in flood after flood until the successive sheets of basalt reached a total thickness of at least 3,500 feet.*

These sheets of lava are interbedded here and there with layers of tuff, old soils, beds of lignite and so forth, showing that they were erupted on land; and the plant remains are similar to those of Bournemouth and Bovey.

The Eocene upheaval had apparently left the eastward slope of the British area unimpaired, but towards its close the sea was pushed southwards from the district round London and the Weald, a process which was probably synchronous with the beginning of the great fold which throws the Chalk into a broad trough beneath London and a great arch over Kent, Surrey, and Sussex. An arm of the central European sea still reached into the Hampshire basin, but during most of the Oligocene period the deposits which accumulated these were either freshwater or estuarine in character. Indeed the Solent, Spithead and the country near, were the broad estuary of the great river we have supposed to have received the drainage of northern Devon.

This differential movement in the south-east of England indicates that change of slope which we needed to explain the Bovey lake, and so far as it goes it shows that Geikie is right in retaining the Bovey beds as Oligocene.

The greater Alpine movements of Miocene time resulted in a still greater change. Hitherto the British area as a

* *Geikie, "Ancient Volcanoes of Great Britain,"* Vol. II, p. 211.

whole had drained south eastward, but the eastern sea had disappeared and the present Atlantic had drawn nearer. Considerable earth movements took place along our southern shores. The old Solent Estuary was compressed from the south, so that the Bagshot beds of Alum Bay and Studland now stand vertical, and a sharp anticline extended through the Isle of Wight and along the Dorset Coast. The Chalk in Dorset was even cleaved by a considerable thrust plane, while the Purbeck rocks near Lulworth Cove were crumpled and puckered. South of this anticline the beds in the Isle of Wight slope gently to the channel. One result of these changes was to cause the drainage of the channel to flow westwards. The south western part of Britain was tilted westwards, while its southern portions were also inclined towards the south. The Bristol Channel and St. George's Channel were also converted into broad valleys draining into the Atlantic, and a broad arm of the North Atlantic pushed its way between the Faroe Islands and Norway until it overflowed even parts of our eastern counties and Belgium.

Such changes were, of course, not suddenly produced. They must have been going on for some time and may not have been completed until the close of the Pliocene period, or even later.

But such reversals of the direction of the great rivers cannot be effected without considerable alterations among their tributaries, and it is to some part of Miocene or early Pliocene times that we must attribute the changes in the drainage of Devon. The westward subsidence of the Bristol channel drew off the Taw and Torridge, breaking their connection near Winkleigh, and severing the Creedy from the Taw, while a southward tilt of the rest of the county, due to the alteration in the drainage of the channel, formed a dividing ridge along the northern edge of the eastern plateau. This last movement, which may be regarded as the continuation of the Isle of Wight and Purbeck anticline, would separate the Culm from the Tone, and reverse the flow of all the rivers of Eastern Devon. At the same time the Exe and Barle would be affected by both movements. To

account for their present course we must suppose some minor tributaries had partly formed the channel south of Tiverton, and when the earth movements came the main stream was turned aside into the nearest possible approach to a south-western course.

The deflection of the Teign and the formation of the Exe estuary may have been brought about in a similar way, which would also account for the turning of the Dart away from the filled-in Bovey lake to something like its present course.

It will be noticed that nothing has been said of the Tamar and its tributaries. The reason is that we have no reason to suppose that any part of its basin, unless it be a small district in the immediate neighbourhood of Plymouth, had ever been submerged beneath the sea since the great upheaval in Permian time. If so, it is a much older river and would have cut so deep a valley through the hard rocks which form its banks that the changes in the slope of the land would be too small to affect it.

Alterations in the geography of the world, such as we have described, would naturally have a profound effect upon its climates. We are not surprised, therefore, to note that the animals and plants whose remains we find in Pliocene deposits show that the period was a time of decreasing warmth, until, at its end, the climate was somewhat similar to what we have at the present day.

Throughout the whole, Devonshire remained well above the sea, but during the later part of Pliocene time it cannot have stood very far above its present level. Marine Pliocene beds are found at heights of 500 feet, capping some of the Kentish Downs, which shows that there must have been a considerable westward expansion of the North Sea. The fact that they are now found only on the summits of the hills is an illustration of that principle to which reference was made when dealing with the gravels of the Devonshire plateau, namely that it is on the hilltops that denudation proceeds most slowly.

On the other hand, filling a cup-shaped hollow in the older rocks, there is a small isolated patch of similar beds

at St. Erth, in Cornwall, thereby indicating a small overlap from the Atlantic.

But the carving of the surface of Devon went on without interruption. Its structure in all except the smallest details was complete, and its history from the close of the Pliocene age until the present is merely the story of its outer garb.

As the Pliocene period drew to its close, glaciers began to form on all the northern mountains and in Wales. Slowly they grew in thickness and spread further and further, and insensibly the world passed from the Tertiary Era into the Pleistocene period, with the great age of Ice.

The Glacial period, as it is called, is one of the greatest puzzles in the whole of the geological record. Books and papers too numerous to count have been written upon it, without arriving at any satisfactory solution of its cause. Some attribute it to a cosmic origin, others regard it as an astronomical event due to exceptional ellipticity in the earth's orbit, while others argue that changes in the distribution of land and sea, by modifying the winds and currents, would be enough to account for all the facts. But whatever theory is advanced, and however well it may seem to meet the case when applied to any particular district, none has been yet devised which meets with general approbation or against which strong arguments cannot be found. The cooling seems to have been world wide, and to have ended not very many thousands of years ago.

Some indications of ice action on a large scale have been detected in the Permian or Late Carboniferous rocks of India, and some geologists have thought that the British Permian breccias indicate the effects of glaciers. But neither of them seem to point to an age of cold in any way comparable with that of Pleistocene times, which stands out as an unique and unexplained epoch in the development of the world.

One thing it did for us. It prepared the world for habitation of early man by exterminating a large proportion of the great beasts of Tertiary time. Both in the Old World and the New the animals of Miocene and Early Pliocene time were larger and fiercer than those of India and Africa

to-day, and some of those whose bones are unearthed from the Tertiary beds of America, Africa and Asia, must have been far more dangerous antagonists than any living beast.

At the culminating period of the cold, a vast glacier covered the whole of Britain down to the Bristol Channel and the Valley of the Thames. A great sheet of ice flowed down from the highlands grinding its way across the lower country, smoothing away its hills, and churning its soil into a great sheet of clay filled with ice-scratched and rounded boulders. As it flowed under the mountain crags great fragments fell on its surface to be carried far and wide, and dropped many miles from their source.

In our eastern counties the hills were thus almost planed away, and the old river valleys were filled in with debris, so that the face of the country was profoundly changed.

Not so in Devon. We have here no indication of glacial action. No ice-scratched boulders, no ancient moraines like those of Wales and Cumberland, no undoubted ice borne blocks, unless we count as such a few great boulders stranded on the shore, as may be seen at Braunton and Croyde. In the east and north of England, beneath the soil, we come in a foot or so to the actual rock but little altered. In Devon the rocks are often rotted and weathered for depths of 20 to 50 feet and more. The deep soils, formed by the water percolating downwards from above through countless years, show plainly that no ice sheet has ever crossed the hills and vales of Devon.

While Northern Britain was thus buried deep under its frozen coat the climate of Devon must have been very severe. The snowfall of the winter must have gathered deep on Dartmoor and Exmoor, then more lofty than they are to-day, and in the early summer when the thaws came, floods of water bearing a heavy burden of detritus must have rushed seawards down all the valleys, scooping them deeper, and spreading half worn gravels widely over the lower ground. Hence came much of the gravels of the lower Exe and those which cap the cliffs at Exmouth and Dawlish—the valley gravels as they are called on the survey maps.

We do not know for certain at what height the country stood, but it is sure that some of the raised beaches around our shores contain shells which point to a colder climate than the present, and the agency of the ice foot or shelf of ice which forms around an arctic shore has been appealed to in order to explain the peculiar features of some of these beaches* and to explain the transport and subsequent stranding of the erratic blocks of Braunton and Croyde.†

On the other hand Professor Bonney has expressed his belief that the glaciation was, in the main, due to great elevation of the whole of Great Britain so that all its higher grounds were above the snow-line. But others have expressed the contrary belief that the marks of ice action, generally attributed to a glacier moving over the land, are really due to fleets of icebergs grinding their way over the shallows as they drifted with the currents of an arctic sea.

Strewn over the hill sides we find the numerous patches of little worn rubbly gravel which may be attributed to the summer thaws acting on the surface of a soil frozen to a depth of several feet. But these again have been otherwise explained. Murchison, for instance, regarded them as having been produced by a terrible cataclysm in the form of a great wave-like rush of water all over the country. Prestwich believed that they were due to a quiet but rapid submergence, too quick for the waves to erode the loose surface rock as they rose, and too slow for the advance of the water to produce a similar effect, and that this was almost immediately followed by a sudden upheaval, so sudden that the retreating water roared seawards on every side like water off the back of a whale. The rapid thaw of a heavy snowfall, and a deeply frozen ground, would soon produce the same effect if repeated year by year, and we prefer an explanation which depends on events which we know occurred, rather than any which demand exceptional causes not otherwise indicated.

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* Pidgeon, *Quart. Jour. Geol. Soc.*, 1890, p. 438.

† McKenny Hughes, *Quart. Jour. Geol. Soc.*, 1887, p. 657.

The great Ice Age waxed and waned, and as the climate improved the country rose again, until a broad bridge must have extended from England to France, a bridge over which the European animals returned to populate the forests and leave records of their presence in caverns like those of Brixham and Kent's Hole, or buried in the river gravels. Once more the forests spread far over the floor of the Bristol Channel and around the shores of Cornwall, stretching we know not how far westward towards the Scilly Isles.

At dead low water of spring tides there are numerous places where tree stumps have been found in the position of growth with their roots spreading out in a soil, with fragments of trees like those now native on the shore. Beds of peat have been found in a similar situation. Moreover the actual channels of the Dart and the Tamar and its tributaries and other rivers lie deep below the present bottom of the sea which fills them. No tidal scour, no action of the present streams could ever have scooped out those valleys to such a depth beneath the sea. They must have been excavated when the land stood at a high enough level for the rock bottom to be at least within the reach of surface movements. This may have been before the Glacial period, but the sides of the submerged valleys conform to those now seen above the mud and sand which fill the lower part, so that it seems almost certain that the valleys and the forests are both Post-Glacial, and belong to the period when the mammoth, rhinoceros and hippopotamus wallowed in the Exe, and when lions, bears, hyaenas, and wolves prayed on the bison, reindeer and Irish elk around Torquay.

The heavy snowfall of the glacial age was followed by a time of much greater rainfall than the present. Gravels and sands were swept headlong from the hills and spread out over the plains, as is seen in the "head" which covers the Bovey clay. The deposits of glacial time, which probably existed in hollows and flatter ground, were scoured away, and the deep river valleys of Pliocene days cut deeper still. But, as a whole, the county presented much the same features

as we see to-day, save that its shores lay far beyond the present coast line.

Among the remains of the post-glacial beasts we find, for the first time in geological history, the implements and handiwork of man. It seems, then, that the vanished land of Lyonesse is not an empty legend, the creation of some ancient poet's brain, but is far more likely a tradition handed down by word of mouth through the ages of human history from men and women who had hunted in its forests and sheltered in its caves. The earliest men of Britain, long-armed and narrow-headed, uncouth in form and primitive in all their ways, but undoubted men, who by their advent marked the beginning of another Era.

Valley of the Otter: Honiton.

Bindon Landslip: The Great Chasm.

CHAPTER XV.

The Modern Scenery.

The ultimate result of the events which have been outlined in the foregoing pages has been to produce a greater variety of contrasted types of scenery than can be found in any equal area within our shores.

In the east of Devon we have the plateau district, carved out of the Eocene peneplain. It is characterised by flat topped hills covered with a shallow stony soil, which has often been left untilled, and is covered with ling and heather, chequered with groves of firs and pines.

From these breezy uplands we look down into the deep valleys whose sides show steep slopes near the summit, where the Eocene and Cretaceous rocks form the subsoil. These precipitous walls are also generally clothed with trees and heath, and are fringed below by a line of springs and boggy ground which marks the top of the Lias, or the red marls—that is, the buried peneplain of Jurassic days.

Below this line the slopes are generally more gentle, and the rest of the valley is occupied by undulating country, most of which is covered with verdant meadows and tall deciduous trees.

The southward inclination of the strata has caused the coast from Pinhay Bay to the Haven Cliff to be fringed with landslips. Most of these are prehistoric, but some are quite modern. Thus on Christmas Day, 1839, nearly forty acres of land broke loose at Bindon Farm and slowly moved seawards. The Chalk and Greensand here rest on a surface of impervious Rhaetic clays, and after an unusually wet year the fox mould was reduced to the condition of a quicksand, and collapsed under the weight of the overlying rocks. A great block of nearly fifteen acres slid seaward, while more than twenty acres either subsided into a great chasm behind the block, or broke up into tall pinnacles and stacks. This great slip was followed in February, 1840, by a smaller one a mile further east where the Blue Lias forms the base.

This is the youngest part of the county, and dates, as has been shown, only from the Eocene upheaval. Indeed the present direction of its drainage is more recent still, since it must be traced to that southward tilt in the middle of Tertiary time which was the last great modifying factor in the history of the district. Nevertheless it should not be forgotten that at least some of the lines of drainage were originally mapped out by irregularities of the emerging surface, caused by the remnants of the hills and valleys which must have marked the underlying Jurassic land surface.

The Great and Little Haldon are, of course, outlying fragments of this eastern plateau. With their exception we find its edge looks down on country of a totally different type.

The ridge which runs through Woodbury Common, Aylesbeare and Whimple up to Burlescombe, marks the outcrop of the Budleigh pebble bed. Until within comparatively recent days it also must have been crowned by a patch of greensand and a strip of the plateau. But this has entirely disappeared, and had it not been for the coarse and porous texture of the pebble bed, and the enduring nature of its component parts the ridge would have been reduced to an undulating country like that on its western side. The stony soil and exposed position fits it for the growth of heaths and firs, and such are its characteristic clothing until, further north, its texture becomes less coarse. Along its base, where the underlying marls crop out, we have the inevitable springs and bogs.

All across the red land until we near its limits, we find the scenery is the result of the varying texture of the red rocks; and on the whole it may be regarded as a larger instance of what we find in the valleys of the plateau.

But this is modified, as we near Exeter, by the irregular appearance of low hills marking the outcrop of the Permian lavas, and by hills of Culm which rise through the red sands and marls.

The Culm hills, as we have shown, must have been there before the red rocks were formed, and in them we have, uncovered to our view after two whole eras of geological

time have passed, the hills and valleys of Permian time. Their slopes have been smoothed and rounded, and the bottoms of the intervening valleys are still buried out of sight. The hard and contorted Culm has resisted the wear and tear of time, the rush of glacial floods and the action of rain and frost, better than the more friable breccias and sands; and so, little by little, the red cloak has been worn away and the hills have grown more and more prominent as they have been uncovered.

Now this difference in the resisting power of the rocks is much less marked where the wear and tear is produced by the grinding and rubbing of gravel upon the bottom of a stream, than it is when the agents of destruction are more gentle.

This is how the channels of the Creedy and the Exe came to be cut through the Permian ridge of Culm which extends across them both near Cowley Bridge. We can only suppose that the courses of both rivers were marked out on the Eocene peneplain above the hills, and that when the streams came down to the Culm ridge it was more easy to cut right across it than to clear another course around the barrier. We have already attributed the beginning of these gorges to some southern tributaries of the Eocene river, perchance the Teign, but they may not have reached the Culm ridge when the southward movement came, and both Exe and Creedy were poured southwards. Those gorges then are not of Permian date, but far later, more likely Miocene or Pliocene, and the floods of the great Ice Age probably had much to do with their excavation.

The limestone hills of Westleigh and the neighbourhood are again partly uncovered Permian, and, if so, those which lie not much further west must be quite uncovered relics of the same distant age. Indeed all the broad region between Dartmoor and Exmoor to the sea at Bude must, as we go westward, differ gradually more and more from that of Permian days, by the increasing amount of wear and tear it has undergone, as it has been longer exposed on the surface. We have no reason to suppose that the greater part of North Devon, including Exmoor, has ever been

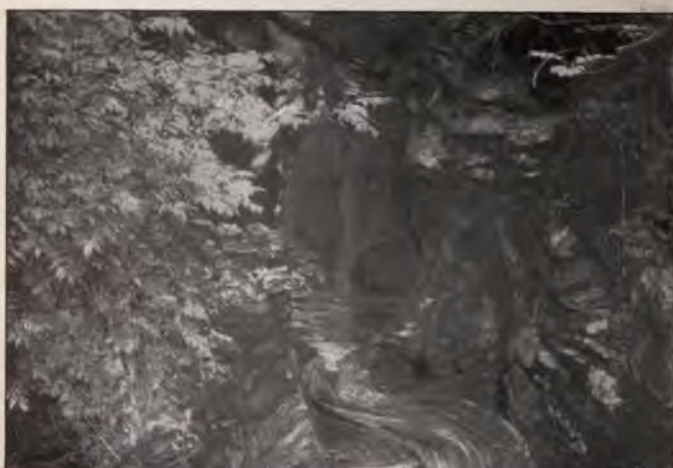
covered with newer deposits. The strip of red land which extends by Crediton, and the smaller tongue at Tiverton were both fjords on the side of the Permian lake, and in the former there were probably Cretaceous deposits. No trace of these has been left in the Tiverton district, and it is unlikely that there ever were any if Mr. Downes is right in stating that there are no flints in the gravels of the upper Exe. The Crediton fjord however was certainly occupied by the waters of the Cretaceous sea, for relics of its presence have been traced to Orleigh Court, not far from Torrington, a few miles from the small patch of red rock in the corner of Bideford Bay. The work of the great North Devon river was to clear this away and lay bare the pre-Cretaceous surface, which must in turn have been modified pre-Permian.

This ancient country is extremely uneven. Its rounded hills, many of which are crowned by bleak and rather desolate moors, are intersected by steep sided and richly wooded valleys, whose slopes and turns have been determined by the varying texture and irregular structure of their crumpled rocks.

Close to the northern margin of the Culm district there rises up a long line of high dome shaped hills which all mark outcrops of the Culm basement beds of radiolarian chert and dark limestone.

North of this line we reach the Exmoor range, the surviving stump of the mountain ridge of the Post-Carboniferous upheaval. The hardened Devonian rocks of which it is built have produced scenery of quite a different type. The great round-topped hills are intersected by deep, narrow, valleys filled with luxuriant woods, still the home of the wild red deer. The great boulders which fill the beds of the tumbling streams are those which are just too big for the winter floods to bear away, but after a stormy day it is easy to hear the smaller pebbles rumbling and grating on the bottom as the work of erosion goes on. So it has gone on, at one time more rapidly, at others slower, ever since the range was formed. Put hundreds of feet of rock into the valleys, and pile hundreds upon the hills, and we should

Lydford Gorge: Pot-holes.



Lydford Gorge: The Deep Cleft.

restore the features of Eocene times. Make those hundreds thousands and we have the mountains from which occasional torrents swept into the Keuper Lake. In many cases we should have the actual courses of those torrents, for none of the movements we have described as having taken place in the Secondary and Tertiary eras were abrupt enough to change the courses of streams with so steep a slope.

Southward across the Culm country we come to Dartmoor, and again the scenery changes. The granite is surrounded by a ring of basement Culm and Devonian rocks which have been more or less baked and hardened by the heat from the molton mass. This altered Culm produces a margin not unlike Exmoor. On the west there is the splendid valley of the Tavy, on the north and east the gorges of the Teign. Further south are the similar scenes of Bickleigh Vale and Holne Chase.

In these valleys, carved out of hard rock, some of the work can be seen to be effected by what is known as pot-hole action. A shallow hollow is formed on the bed of the stream, or a few large boulders happen to lodge so as to form a kind of cup into which the water pours in such a way as to produce a swirling movement. If, now, some stone is swept into the cup small enough to be pushed round and round, but too large to be easily carried away, it slowly abrades the rock, forming a rounded basin which is gradually deepened. Two neighbouring pot-holes enlarge until they join; then the division clears away and in time the process begins again.

Lydford Gorge, where the little Lyd crosses the aureole of altered rock, has been almost entirely made by this process. The narrowest and most sombre part of the gorge shows innumerable smooth rounded sections of such holes, some of which are far better than any diagram. The stream falls and rushes along the bottom of a chasm from seventy to eighty feet deep, and in places not more than fifteen feet wide. Truly an awe-inspiring place if visited when the snow is thawing quickly on the moor, or after some days of heavy rain when the swollen waters fill the

great crevasse with a thunderous roar, and the black walls are dripping wet with a mist of spray.

Lower down, where the ring of altered rock is crossed, the valley opens out, but narrows again where it nears a patch of volcanic rock, and then gradually opens wider and wider as the rocks become more distant from the granite.

The granite area of the moor itself is bleak and bare. It contains none of the deep wooded vales such as abound among the northern heights, and the summits of its hills are often crowned by rugged piles of naked rock called tors.

The sandstones of Exmoor, the grits of the Culm, and, indeed, most rocks, when exposed to the weather, or to water which has percolated through the soil, break up into small pieces which are soon rounded into pebbles. With granite this is the exception and not the general rule. Again, granite does not yield to abrasion much more easily than sandstone, but when exposed to the weather it has nothing like the same power of resistance. The contrast is well seen in the ruins of Okehampton Castle. The weather of some centuries has beaten on these old walls, and blocks of granite in them are deeply corroded, so that they can be crumbled away and bits can be rubbed out of them with the fingers, but other stones of red sand from Hatherleigh seem quite unchanged, and still show the marks of the mason's chisel.

Soft rocks like the unaltered Culm or Devonian shales are very easily removed, either by flowing water, or by exposure to the weather. But if such beds are intermixed with grit and sandstone, the coarser debris these produce is not easily removed by the weather; it requires the action of running water. If sufficient water power is available the hard fragments make hard pebbles which are exactly the tools for digging away the river bed. Thus, in a Culm or Devonian country the rivers abrade their beds rapidly, but the valleys do not open wide. The coarse fragments of the harder beds must lie on steep slopes before they can be moved.

If the shales also are hardened by heat they resist the weather almost as well as the grit, but both yield hard

pebbles, and the result is deep valleys with precipitous sides, like Fingle Gorge upon the Teign, or in an extreme case the narrow fissure made by the Lyd.

The peculiar properties of granite, whereby the undecomposed stone is hard and well able to resist abrasion, but the stone itself is somewhat easily rotted by the weather, results as a rule in shallow, wide open, valleys with comparatively gentle slopes.

This weathering of the granite is worthy of more consideration. If the face of the rock on one of the projecting tors is examined it will be seen that the feldspar has become opaque, and that its larger crystals with the larger grains of quartz project on the surface. The finer matrix in which these were embedded has crumbled away. Beneath the soil it is no uncommon thing to find this crumbling has penetrated far below the surface, so that the rotten rock can be dug out with a spade, but the process is uneven. The granite mass is naturally split up by joints into great more or less cubic blocks, all of which are large and heavy, some very large indeed. Some of these blocks seem able to resist the action of weathering agents, and remain practically unchanged, while their neighbours have been reduced to the consistency of a coarse sandy clay. Two very different types of debris are thus produced, a fine kind easily removed from a slope and requiring only a gentle stream to sweep it away, and an exceedingly coarse kind, too large to be moved by anything short of a rushing torrent in heavy flood. There is hardly any of that medium sized hard debris which is the principal product of sandstones, grits, cherts or flints—material small enough to be fairly easily moved, and yet coarse enough to act as efficient abrading tools, such as was the chief agent in carving the deep valleys of other districts.

Dartmoor streams are therefore thickly cumbered with these great boulders, and the surface of the moor is strewn with them, where the removal of overlying and surrounding crumbled rock has left them lying.

The tops of the hills are at first rounded, showing a convex contour which becomes concave lower down, and

the steepest part is where the character of the curve changes. Now with such a mixture of very coarse and fine debris the sides of the hill will be wasted more rapidly than the top, and the concave slopes will draw gradually together and extend higher up the hill, until they reach the summit, and then the hill becomes pointed, with slopes which get steeper as they near the top.

At the top of such a hill the fierce gales of winter drive the heavy rains with great violence, and soon remove the finer products of decay, leaving nothing but a pile of the unrotted blocks. A pile of blocks once formed protects the granite beneath it both by directly shading it from rain, and still more by the absence of soil. It is the products of vegetable decay which are the most powerful agents of destruction, and rain which has not soaked through any soil is far less potent. The result is that the ground around the tor continues its general descent, but the erosion of the tor itself is far more slow.

Exactly the same processes account for the crags that often mark the outcrop of the crystalline rocks or lavas of the Teign Valley and round Brentor, but the rocks which form those summits are not naturally divided into great semi-cubic masses like those of granite. Hence we may have other tors such as Bottor, but they have not the same features.

The barrenness of the Moor is due partly to the bleak winds of winter, but also to a large extent to the nature of its soil. The decomposition of the rock resulting in a mixture of sand and clay, the subsoil is too frequently water logged, and the surface consists of peaty bogs. Properly tilled and drained, even the higher parts may be brought under cultivation.

The average surface of the Moor is high above the surrounding country, because its general rate of waste is less than that of even the hardened Culm and Devonian rocks. This seems at first sight almost a contradiction to what has been said of the rate at which granite rots; it is not really so. The rate at which a country is planed away depends far more on the speed with which its rivers

The Crown of the Moor: Yes Tor.

The Edge of the Moor: Valley of the W. Okement.

can dig their channels deeper. For the reasons given, the streams on the granite deepen their channels very slowly, and the surrounding rocks may rot, but the materials cannot get away; on the other hand in a district which yields abundant debris of the right size the valleys deepen quickly, and when any of the intervening rock does give way to the action of the weather, it is soon removed and a fresh surface exposed.

The granite, as a whole, then forms a projecting highland and its edge is thus frequently trenched by the streams where they rush down to the lower ground, but these valleys suddenly narrow when the granite is left.

The greatest heights are on the northern and western edge, and a broad hollow extends from the line of the Bovey basin to Chagford. This has been attributed to a shallow synclinal sinking during Tertiary time. It may be so, and may therefore be due to a part of the change which altered the river system.

But it must not be forgotton that the Moor has been a land surface ever since its superincumbent volcanic peaks first arose above the waves of the Devonian Sea. Those peaks must have mapped out a drainage system among themselves while they were still active volcanoes, and such a drainage system must on the whole have persisted long after they had become extinct. The valley bottoms dug deeper and deeper into the mass of lavas and tuffs and possible Culm rocks, until some of them reached the granite and portions of it were carried down to be strewn in the Permian breccias.

The contours of the granite would thus tend to retain some slight resemblance to those which had gone before, and it is more than possible that in the valleys and basins of the present Moor we have a fainter copy of its surface long ago.

Three thousand five hundred feet of basalt have been removed from the west of Scotland, according to Geikie, since early Tertiary time. Many thousands must then be piled on the surface of modern Dartmoor, if we would restore it to what it was when the great flood of lava rushed

from some vanished cone to pour down past Posbury, Pocombe, Exeter and Poltimore.

Still one more type of scenery is found in southern Devon, from Newton Abbot to Plymouth. It is a smoothed and softened copy of the north, but varied by the irregular distribution and variety of its component rocks. Limestones and volcanic bosses diversify the landscape, causing the slopes to change abruptly and irregularly. The deep valleys are varied by bold bluffs and gently sweeping curves, while they are continued seaward by long branching fjords. These are no sea-wrought inlets, but only drowned portions of the valleys, and the beds of the streams which made them now lie buried far beneath the mud which paves the present channels. The broad alluvial plains which in recent times have filled up the estuaries of the Exe and Axe are made of gravels lodged in broader valleys which were similarly submerged, and the process is still going on. We know that in Roman times and later, the estuary of the Axe was an important harbour, and indeed it was in use so recently that the harbour quay is still in good repair.

Such minor changes however have made little alteration in the whole, but are enough to show that the making of scenery is still progressing. The same agents of erosion and reconstruction are busy as of old, and it is by watching them at work that we can learn how they have worked before.

A new factor has been added to the great physical forces of Nature in the restless energy and enterprise of man. Men hew the forests, drain the marshes, dam the rivers, and obstruct the waves. But great as is the effect they can produce upon the landscape, all their efforts do little more than modify the surface. They cannot yet control the floods, nor stay the storm. Volcanoes and earthquakes still exist, but we have no means of knowing whether the greater earth movements might or might not still occur. It may be that the world has reached a stable state, that its frame work has attained its final condition, like the bones of a full grown man; but it is equally

likely that the vanished continents may again arise, and new mountain chains grow from the ocean floor.

However this may be, many of the processes which have made our county what it is are still at work, changing and modelling anew its ancient frame. But some traces of its present form must always be, for it is just as true of the making of scenery as it is of human history or human character, that the past has made the present, and the present shapes the future.

ERRATA.

Page	49,	line	27,	for	learn	read	*hear.*
,,	80,	,,	17,	,,	Vucanello,	,,	*Vulcanello.*
,,	143,	,,	19,	,,	Beer Common	,,	*White Cliff Fall.*

Illustration facing p. 104, for Sea Green read *Tea Green.*

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